AGRICULTURAL ENERGY CENTRE

METHODS TO UTILIZE TOBACCO KILNS
FOR CURING (DRYING)
AND/OR
STORAGE OF ALTERNATE CROPS
-interim report - 1988 year

REPORT NO. 89-5103 MARCH, 1989

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By:

D. L. Van Hooren, P.Ag.
Agricultural Energy Specialist
Agricultural Energy Centre
Ontario Ministry of Agriculture and Food
Research Station
Delhi, Ontario

and:

A. J. Ratavicius
Agricultural Energy Centre
Ontario Ministry of Agriculture and Food
Research Station
Delhi, Ontario

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ABSTRACT

Methods to utilize tobacco kilns for conditioning of crops other than tobacco were investigated. Ginseng, popcorn, flowers, spanish onions and sweet potatoes were either dried or cured in tobacco kilns. After curing, sweet potatoes were the only crop stored in tobacco kilns. Results indicate that tobacco kilns can be modified to condition these crops provided that the appropriate air conditions can be attained in the kilns.

In addition, the effects of curing air flow and air relative humidity in relation to peanut quality were investigated. Peanut quality did not appear to be affected by air flow rate or air relative humidity used during curing.

INTRODUCTION

In recent years Ontario tobacco producers have had to reduce production levels due to a declining demand for flue-cured tobacco. Some tobacco producers have ventured into growing other crops to supplement their income from tobacco. Some of these crops require curing and/or storage. Because of high capital costs to purchase conventional curing and/or storage facilities for these crops, many producers would like to reduce their initial costs of diversifying into other crops by modifying their existing tobacco kilns and/or tobacco storage barns for this purpose.

Every flue-curing tobacco farm in the province is equipped with either stick or bulk kilns. The number of kilns on each farm varies, however, there are usually at least 8 kilns per farm. In addition, each farm has one or more tobacco storage barns (commonly referred to as pack barns). Appendix A describes these structures in further detail.

There is limited information available on modifying tobacco kilns and barns for curing and/or storage of crops other than tobacco. In addition, curing and/or storage guidelines for some alternate crops is based on climatic conditions in the United States and require adaptation to Ontario climatic conditions. Since 1982, the Agricultural Energy Centre of the Ontario Ministry of Agriculture and Food has been assisting tobacco producers with developing methods to use their tobacco kilns and barns for curing and/or storage of crops other than tobacco.

During 1982 and 1983, the Agricultural Energy Centre investigated the merits of utilizing tobacco kilns to cure peanuts. An on-farm demonstration project proved that bulk kilns can be successfully used for this purpose (Van Hooren and Columbus, 1983). Another farm project in 1987 proved that sweet potatoes can be cured and stored successfully in bulk tobacco kilns (Van Hooren, 1988). Also in 1987, with financial assistance from the Alternate Enterprise Initiative Program, three projects were undertaken to investigate curing and/or storage of alternate crops in tobacco kilns: i) drying and storage of shelled corn; ii) effects of air flow rates in

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The mention of manufacturer's trade names is for the purpose of specific product description and does not indicate endorsement or criticism of that product or products not mentioned by the authors or the Ontario Ministry of Agriculture and Food.

relation to the curing and quality of peanuts; and iii) curing of hay (Van Hooren and Scott, 1988). Results from the three projects indicated that i) shelled corn can be dried in bulk kilns from about 26% moisture content (w.b.) or less ii) peanuts cured in test kilns at air flow rates ranging from 169 to 645 litres per second per cubic metre of peanuts exhibited no significant differences when evaluated for appearance and flavour; and iii) baled hay can be dried in bulk kilns from about 27% moisture content (w.b.) or less.

In 1988, again with financial assistance from the Alternate Enterprise Initiative Program, the Agricultural Energy Centre undertook six projects to further develop techniques for utilizing tobacco kilns for curing and/or storage of the following crops: popcorn, ginseng, peanuts, spanish onions, dried flowers and sweet potatoes. The findings of each project are documented in sections i) to vi) of this report.

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i) EFFECTS OF CURING AIR RELATIVE HUMIDITY AND AIR FLOW IN RELATION TO CURING AND QUALITY OF PEANUTS

BACKGROUND

Commercial production of peanuts is relatively new to Ontario. The first commercial crop of peanuts, about 70 ha, was grown in 1980. Peanut production has gradually increased since then to about 325 ha in 1988.

In Ontario, peanuts are harvested at 55 to 65% moisture content (w.b.) and must be cured to a safe storage moisture content of 10% (w.b.) or less. As compared to curing procedures used by peanut growers in the south-eastern United States, Ontario grown peanuts must be cured from a higher initial moisture content.

In the United States, peanuts are dug, windrowed and field cured to about 20 to 30% moisture content (w.b.) prior to mechanical curing. Field curing is not possible in Ontario because of the possibility of frost at night during the harvest season of late September and October. Green peanuts which are frozen will have a "bad" off-flavour and are not marketable. Thus, curing Ontario grown peanuts is more energy intensive than U.S. curing methods.

In the United States, the majority of peanuts are cured in specialized peanut dryers. Many Ontario peanut growers cannot afford these dryers and are using modified bulk tobacco kilns to cure peanuts.

During 1982 and 1983, the Agricultural Energy Centre conducted an on-farm demonstration project which compared the energy efficiency of various tobacco kilns to cure peanuts (Van Hooren and Columbus, 1983). The project also investigated two different curing methods: 1) no recirculation of air during the entire curing process as compared to 2) no recirculation of air during the initial stages of curing followed by partial recirculation of air during the latter stages of curing.

Results from the project indicated that batch curing of peanuts in bulk tobacco kilns was the most energy efficient curing method (as compared to using other tobacco curing facilities). Peanuts cured in bulk tobacco kilns using the combination of no-recirculation of air during the initial stages of curing and partial recirculation of air during the latter stages of curing required about 12.8 megajoules (MJ) of energy in the form of natural gas and electricity per kilogram of in-shell peanuts.

PROBLEM IDENTIFICATION

The Alternate Crop Section, Agriculture Canada Research Station, Delhi, Ontario, provides peanut growers with curing guidelines (1988). A brief description of the curing guidelines is as follows.

Temperature Curing air temperature should not exceed 35°C. Temperatures above 35°C increase the proportion of off-flavoured and split peanuts.

Humidity Excessively low or high humidity curing air must be avoided. High humidity promotes mould formation, sprouting and off-flavour whereas low humidity promotes rapid drying and results in poor milling characteristics (ie. splits). When the ambient air relative humidity is 50% or greater, the air should not be heated by more than 10 to 20C°. When ambient relative humidity is below 50%, no additional heat is required for the curing air. (In Ontario, during late September and October, the ambient relative humidity is usually greater than 50%).

Air Flow Curing peanuts with a moisture content between 55 to 65% (w.b.) requires a blower capable of pushing a minimum of 500 litres per second per cubic metre ($L/s/m^3$) of peanuts. An air flow rate below 500 $L/s/m^3$ of peanuts decreases the drying rate and may allow moulds to develop which could result in off-flavour.

Most Ontario peanut growers are limiting the maximum curing air temperature to 30°C, which is 5C° less than the recommended maximum curing air temperature of 35°C. Since the majority of peanut growers are using bulk tobacco kilns to cure peanuts, the fuel energy input of the kilns' burner units is limiting the temperature rise of the ambient air to 20 C° or less during the stage of curing when air is not recirculated. Thus, the peanut growers do not have to adjust kiln thermostats during curing to prevent ambient air temperature rises above 20C°. However, many peanut growers are curing peanuts with an air flow rate less than 500 $L/s/m^3$ of peanuts.

Table 1P indicates the air flow rates measured during peanut curing in 180 rack size, "DeCloet" bulk tobacco kilns at a farm site in October of 1986. The measured air flow rates ranged from 264 to 319 $L/s/m^3$ of peanuts. This is about 35 to 50% less than the recommended air flow rate of 500 $L/s/m^3$ of peanuts.

The effects of air flow rates in relation to curing and quality of Ontario grown peanuts is not known. Literature from the United States, upon which Agriculture Canada curing guidelines are based, suggests that to prevent the growth of mould which could result in off-flavour, a minimum of 500 L/s/m³ of peanuts is required for peanuts at 50% moisture content (w.b.) or greater (Glover 1970).

Ontario peanut growers and processors have indicated that the quality (ie. taste and appearance) of peanuts cured in bulk tobacco kilns is generally good, however, not always consistent.

In 1987, a project funded by the Alternate Enterprise Initiative program was initiated to determine the effects of air flow rates of 500 L/s/m³ of peanuts or less in relation to the curing and quality of Ontario grown peanuts. Results of the project are documented in a report entitled "Development of Technology to Utilize Existing Tobacco Kilns and/or Tobacco Storage Barns for Curing (Drying) and/or Storage of Other Crops", Report No. 88-5103, Agricultural Energy Centre. Project results indicated that peanuts cured at air flow rates ranging from 169 to 645 L/s/m³ of peanuts exhibited no significant differences when evaluated for appearance and flavour.

In 1988, the project was repeated to verify the results from 1987. In addition, the project was expanded to investigate the effects on curing and quality of peanuts when cured at a relative humidity of about 50%. This coincides with the recommendation on curing air relative humidity put forth by the Alternate Crop Section, Agriculture Canada Research Station. It states that ambient air at 50% relative humidity or less requires no additional heat to cure peanuts. Thus, if only enough heat is used to limit the curing air to about 50% relative humidity throughout the curing process, then optimum curing conditions for peanuts should result.

OBJECTIVES

Determine the rate of drying (% moisture removal per hour), curing fuel energy requirements and effects on quality when 1.) peanuts are cured with air flow rates of 500 L/s/m³ of peanuts or less 2.) or cured with air that is at 50% relative humidity.

METHOD

Peanut Curing Chambers

The project was conducted at the Agriculture Canada Research Station, Delhi, Ontario. Nine "mini-bulk kilns" at the Station were used for the project (see figure 1P).

The mini-bulk kilns (mini-kilns) are basically of the same configuration as full-size bulk kilns, with one exception, the loading capacity of each mini-kiln is 1/75th that of a 150 rack bulk tobacco kiln. In addition, unlike most bulk tobacco kilns which are heated with natural gas or propane, each mini-kiln is equipped with a 2 stage, 3 kW electric resistance heater.

A "B Baby Vent" centrifugal blower powered by a 0.2 kW motor circulates the air within the mini-kilns in the same manner as in full-size bulk kilns. Air is forced into a lower plenum and up through a perforated metal floor. After the air has passed through the product (in this case peanuts) it either returns to the blower for recirculation or is expelled from the kiln through a pressure sensitive exhaust vent.

Curing Air Flow Rates

Seven of the 9 mini-kilns were used to cure peanuts at different air flow rates. From one of the authors' previous experience using these kilns for curing peanuts in 1987, it was known that loading peanuts to a depth of 480 to 535 mm in the mini-kilns results in an air flow of about 500 L/s/m^3 of peanuts (depending upon debris within the peanuts). It was decided that increasing the peanut depth from 480 mm by increments of 55 mm, similar to the loading depths used in the 1987 project, would ensure incremental decreases of the air flow rate. This would result in a range of air flow rates and would include rates used by the majority of peanut growers.

The loading depth selected for each mini-kiln is indicated below:

KILN (K)	PEANUT LOADING DEPTH
K1	480 mm
K2	535 mm
K3	590 mm
K4	645 mm
K5	700 mm
K6	755 mm
K7	810 mm

Curing Air Relative Humidity

Two of the 9 mini-kilns were each equipped with a "Honeywell, model no. H600A 1014" humidistat for controlling the curing air relative humidity. In one of the mini-kilns, K8, the humidistat was positioned in the lower plenum below the perforated floor. In the other mini-kiln, K9, the humidistat was positioned in the upper plenum above the peanut layer.

Each humidistat was connected in series with the mini-kiln's thermostat to control the cycling of the heater in relation to the curing air relative humidity: at relative humidities above 50% the heater would cycle ON and below 50% the heater would cycle OFF. The maximum curing air temperature was limited by the thermostat setting.

Since K1 was being used as the check kiln for the air flow portion of the project, it was decided that it would also serve as the check kiln for the curing air relative humidity portion of the project.

The loading depth of K8 and K9 was 480 mm each, similar to the loading depth of K1.

Curing Procedure

The peanuts cured were of the Garroy variety and were dug with a once-over harvester. The peanuts were not washed prior to curing, thus plant debris and soil harvested with the peanuts were dried as well. Curing commenced immediately after the mini-kilns were filled.

The curing schedule used for the project was identical to that used by most Ontario peanut growers. Each kiln thermostat was set at 30°C. Similar to full-size kilns, the curing air temperature is limited by the output capacity of each mini-kiln's electrical heater. The curing air temperature can not exceed the ambient air temperature by more than 20C° when air is not recirculated in the kiln.

During the initial stage of curing, the loading doors of the mini-kilns remained open. The air return intake of each kiln's blower was blocked until the hulls of the peanuts at the top of the peanut layer in each kiln were dry (when the peanut kernels rattled in hull). At this time the return air intake to the blower was opened and the doors were closed until completion of curing.

Moisture samples were taken when the doors of each kiln were closed and thereafter each day until the moisture content of the peanuts decreased to 10% (w.b.) or less. Once this was attained the heater was turned off and the blower remained on until the peanuts had cooled to ambient air temperature.

The mini-kilns used for curing peanuts at different air flows were loaded and cured thereafter on the following dates:

Cure 1 - September 19/88;

Cure 2 - September 29/88;

Cure 3 - October 7/88;

Cure 4 - October 17/88.

The mini-kilns used for curing peanuts at a constant curing air relative humidity were loaded and cured thereafter on the following dates:

Cure 1 - September 19/88;

Cure 2 - September 29 & 30/88;

Cure 3 - October 17/88;

Cure 4 - October 31/88.

MONITORING

A "Kaye-Digi III" datalogger and type T thermocouples were used to record dry-and wet-bulb temperatures of the curing air in the lower plenum (before the curing air entered the peanuts) of each mini-kiln. Ambient air dry-and wet-bulb temperatures were also recorded during curing.

An "Alnor" velometer was used to measure the air flow through the peanuts in each mini-kiln used for the air flow portion of the project. The velometer covers an area of 350 mm x 350 mm and measures air velocity with a set of pitot tubes. The meter is calibrated to indicate the resultant air flow rate in cubic feet per minute.

Each mini-kiln is equipped with a kWh meter which measures the electrical consumption of the heater. The kWh meter readings were recorded daily during curing.

Initial moisture content of the peanuts was determined using an oven dry method of 130°C for 7 hours. A "Stienlite Model D" electronic moisture meter was used to determine the final moisture content of the peanuts. The moisture meter was calibrated prior to use based on the oven dry method utilized for initial moisture content determination.

RESULTS AND EVALUATION

Air Flow Rates

Table 2P shows the results of curing peanuts at different depths in the 7 mini-kilns to achieve different air flows through the peanuts.

The initial moisture content of the peanuts cured over the four cures ranged from 64.89 to 75.35% (w.b.). The final moisture content of the peanuts ranged from 8.24 to 10.20% (w.b.).

Increasing the peanut depth in the mini-kilns from 480 mm (in K1) to 810 mm (in K7) by increments of 55 mm per kiln resulted in air flows ranging from 586 to 622 L/s/m^3 of peanuts in K1 to 303 to 319 L/s/m^3 of peanuts in K7 over the 4 sets of cures. The latter air flows correspond to those measured at the farm site in 1986 (described in PROBLEM IDENTIFICATION section). Thus, the data provides some insight as to the effects of curing Ontario grown peanuts at different air flows.

The data indicates that curing peanuts with an air flow less than the recommended 500 L/s/m^3 of peanuts increases the length of time to cure peanuts. Peanuts cured at air flow rates of 303 to 319 L/s/m^3 of peanuts required 6.5 to 31.5 h longer to cure than at air flows of 491 to 622 L/s/m^3 of peanuts over the 4 sets of cures.

The drying rate (% moisture content reduced per hour, % m.c./h) was also affected by the air flow rate. Figure 2P illustrates that the drying rate decreased as the air flow rate decreased. At air flow rates of 586 to 622 L/s/m^3 of peanuts cured in K1, the drying rate ranged from 0.40 to 0.42 % m.c./h whereas at air flow rates of 303 to 319 L/s/m^3 of peanuts cured in K7, the drying rate ranged from 0.33 to 0.37 % m.c./h.

The variation in air flow rates at identical depths over the 4 sets of cures can be attributed to the amount of debris contained amongst the peanuts. As shown in table 3P, the amount of debris differed for each kiln over the 4 sets of cures. In most instances, higher percentages of debris created more resistance to air which decreased air flow through the peanuts.

Curing Air Relative Humidity

Table 4P shows the curing results from using humidistats, set at 50% RH, to control the curing air RH in K8 and K9 as compared to the check kiln, K1, over 4 sets of cures. (No data was recorded for K9 for the 1st set of cures because the humidistat was on back order).

The length of time to cure peanuts in K8 and K9 ranged from 218.7 to 332.0 h while in K1 curing time ranged from 139.5 to 161.3 h over the 4 sets of cures. Figure 3P illustrates that the drying rate ranged from 0.18 to 0.26 % m.c./h for peanuts cured in K8 and K9 as compared to 0.40 to 0.44% m.c./h for peanuts cured in K1 over 4 sets of cures. Thus, it appears that controlling curing air relative humidity with humidistats, set at 50%, results in longer curing time and a slower rate of drying as compared to the conventional method for curing peanuts.

Figures 4P and 5P illustrate the hourly averages of air dry-bulb temperature and its corresponding relative humidity recorded over the 3rd set of cures for kilns 1, 8 and 9.

The graphs indicate that the air dry-bulb temperature for K1 was limited to 30°C for most of the cure, however, it did drop below 30°C twice. This occurred when the ambient air temperature was 20C° less than the thermostat setting of 30°C. It was expected that this would occur because the maximum heating capacity of the heater is limited to 20C° above the ambient temperature. The air relative humidities at the air dry-bulb temperatures recorded for K1 decreased from a high of about 55% to 30% during the initial 30 h of curing. Thereafter, the air relative humidities fluctuated between 22% and 30% for the remainder of the cure.

The air dry-bulb temperature for K8 was also limited to 30°C by the thermostat, however, for the majority of the cure it was below 20°C. This was a result of the humidistat, located in the lower plenum of the kiln, controlling the heater. Since the humidistat was set at 50% RH, (but actually limited it between 45 and 55% R H,) the air dry-bulb temperature could not exceed the temperature required for an air relative humidity of 50%.

The air dry-bulb temperature for K9 fluctuated between 10 and 30°C over the majority of the cure. This was a result of having the humidistat located in the upper plenum above the peanut layer. The curing air relative humidities fluctuated constantly from about 35% to 70% over the majority of the cure. It can be assumed that this was a result of the humidistat not detecting a change in curing air conditions until the drying front had passed through the peanuts. Curing air temperatures and relative humidities recorded for the other sets of cures indicate similar results to that of the 3rd set of cures. It would appear that controlling the curing air relative humidity with a humidistat requires it to be located in the lower plenum (before the curing air enters the peanuts).

Peanut Quality

Physical Characteristics:

Tables 5P and 6P show the physical characteristics of peanuts cured in the mini-bulk kilns used for the air flow and relative humidity portions of the project. The data is based on samples taken from each kiln cured.

The total percentage of sound mature kernels (referred to as SMK where the kernel size is greater than 5.95 mm) ranged from 41.0 to 52.5% over the cures. The % pick, a combination of discoloured, mechanical damaged and split peanuts, ranged from 0.6 to 29.1. It should be noted that the % pick for 4th set of cures in the relative humidity portion of the project ranged from 17.4 to 29.1. It can be assumed that the lateness of harvest and a severe frost prior to harvesting were responsible for the large percentage of discoloured peanuts.

Seed Viability:

Four samples of 25 peanuts (SMK grade) from each cure were germinated to determine seed viability. Each sample was treated with Granox P.F.M. (a peanut fungicide consisting of captan and maneb) at a rate of 3.8 g/kg of peanuts. Each sample was placed in a petri dish containing 10 ml of water and placed in a "Con Enviro" growth chamber at 21°C and 100% relative humidity. Germination counts were conducted after 96 hours.

Tables 7P and 8P show the % seed viability of peanuts cured in the mini-kilns used for the air flow and relative humidity portions of the project. There does not appear to be any relationship between % seed viability and curing air flow. The peanuts cured at a controlled curing air relative humidity also show no effects on % seed viability for the first 3 cures. However, the last set of cures, cure 4, show a significant reduction in % seed viability. Since K1 (check kiln) also shows a similar reduction in % seed viability it appears that the lateness of harvest was responsible for the reduction in seed viability and not because of controlling the curing air relative humidity.

Appearance and Flavour:

A random, shelled sample of the SMK grade was selected from each kiln for all cures. The samples were picked (visually) to remove any foriegn

objects. Splits and discoloured peanuts were not removed since these peanuts may have resulted from the curing process. About 1000 g of peanuts from each sample were roasted in peanut oil at 150°C and then cooled afterwards.

A panel of 8 people evaluated the appearance and flavour of the peanuts cured at the different air flows and controlled curing air relative humidity.

Since Ontario grown peanuts are not blanched prior to marketing, the panel evaluated the appearance of the peanuts based on skin colour. The following point scale was used by panel members to evaluate the appearance of the peanuts:

3 - good

2 - fair

1 - poor

The "revised" Critical Laboratory Evaluation of Roasted Peanuts (CLER) scoring method was used to evaluate peanut flavour and off-flavour (Fletcher, 1987). The following point scales were used by the panel members to evaluate the peanuts according to degree of peanut flavour and off-flavour.

Peanut Flavour:

5 - high

4 - moderate to high

3 - moderate

2 - low to moderate

1 - low

0 - none

Off-Flavour:

0 - high

1 - moderate to high

2 - moderate

3 - low to moderate

4 - low

5 - none

Figure 6P shows the evaluation sheet used by the panel members. Each panel member evaluated 20 individual peanuts from each kiln of peanuts cured. The panel members' appearance scores for each kiln of peanuts were added together and averaged out of 100. The panel members' scores for peanut flavour and off-flavour for each kiln of peanuts were also added together, divided by 2, and averaged out of 100.

An acceptable score for appearance is a value greater than 50 and for flavour a value between 50 to 100.

Tables 9P and 10P show the appearance and flavour scores for peanuts cured at different air flows and at controlled curing air relative humidity.

The appearance scores for peanuts cured at different air flows were generally above 90. There is no indication that the air flows used affected the appearance of the peanuts. The flavour scores for peanuts cured at different air flows were in the acceptable range of 50 to 100. There is also no indication that the air flows used affected the flavour of the peanuts.

The appearance scores for peanuts cured at a controlled curing air relative humidity do not significantly differ from that of the check kiln. The flavour scores were all in the acceptable range of 50 to 100 and also do not significantly differ from peanuts cured in the check kiln. It should be noted however that the appearance and flavour scores for the 4th set of cures were the lowest of all cures sampled. Again, this is probably a result of the lateness of harvest and a frost prior to harvesting.

Fuel Energy Consumption

Tables 11P and 12P indicate the fuel energy consumed to cure peanuts at different air flows and at a controlled curing air relative humidity.

K1 consumed more fuel energy per kg of water removed from the peanuts than K2 to K7. Indications are that decreasing the air flow rate through peanuts decreases the fuel energy consumption. However, one must not forget that the length of time to cure the peanuts increased as the air flow rate decreased. Unfortunately the electrical consumption of the kilns' fans was not monitored and thus the electrical consumption cannot be evaluated.

The fuel energy consumption for peanuts cured at a controlled relative humidity varied somewhat from that of the check kiln (K1). In some instances the controlled curing air relative humidity cures consumed about half as much fuel as that of the check kiln while for other cures it was similar to that of the check kiln. However, again one must not forget that the fans ran considerably longer in the kilns that were operating at a controlled curing air relative humidity and that the total electrical consumption of these kilns was probably significantly greater than that of the check kiln.

CONCLUSIONS

1.) Decreasing the air flow rate below 500 L/s/m^3 of peanuts increases the length of time to cure peanuts.

2.) The drying rate of peanuts decreases as the air flow rate decreases below 500 L/s/m^3 of peanuts.

3.) The appearance and flavour of peanuts is not affected when cured at air flow rates ranging from 303 to 622 L/s/m^3 of peanuts.

4.) Fuel energy consumption required to cure peanuts decreases as the air flow rate is decreased below 500 L/s/m^3 of peanuts.

5.) Debris amongst peanut pods increases air resistance and decreases air flow.

6.) A humidistat positioned in the lower plenum of a kiln, below the peanut layer, can effectively control the curing air relative humidity. Positioning the humidistat in the upper plenum of a kiln, above the peanut layer, does not effectively control curing air relative humidity.

7.) Controlling the curing air relative humidity at 50% results in longer curing time and a slower drying rate as compared to conventional peanut curing techniques.

8.) Peanuts cured at a controlled curing air relative humidity exhibited no differences in appearance and flavour as compared to those cured by conventional techniques.

RECOMMENDATIONS

The results of the air flow portion of the project do not differ significantly from results found in 1987. The air flow and controlled curing air relative humidity projects should be continued in 1989 to confirm results from the preceeding year(s).

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Figure 1P: Mini-bulk kilns used for curing peanuts

Fig.2P: PEANUT DRYING RATE AT DIFFERENT AIRFLOWS OVER 4 SETS OF CURES

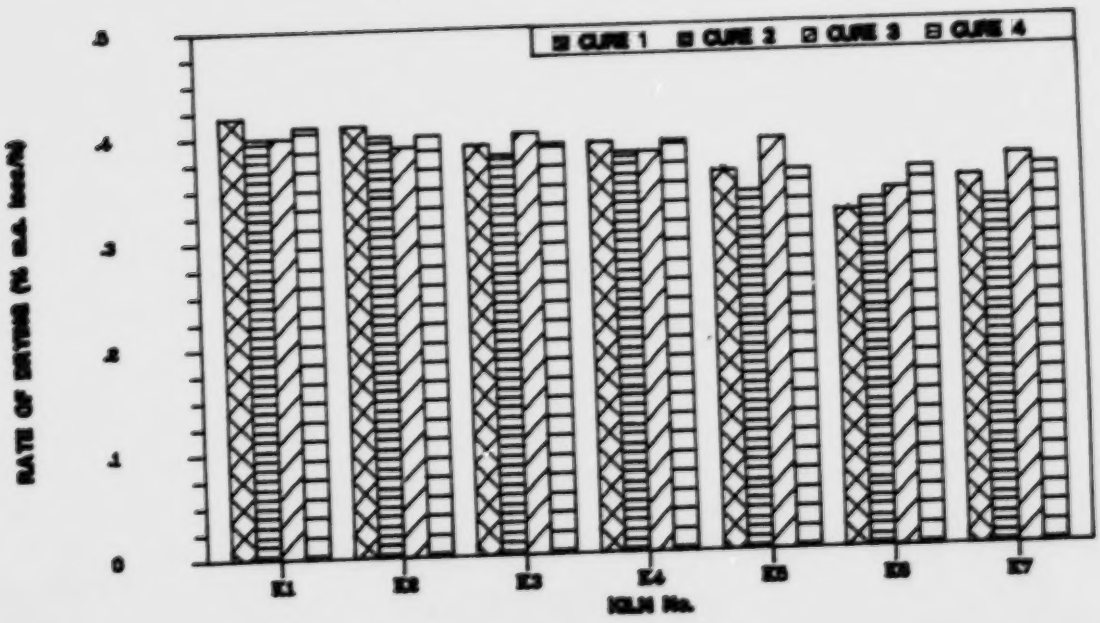

Fig.3P: PEANUT DRYING RATE AT DIFFERENT CURING AIR RELATIVE HUMIDITIES

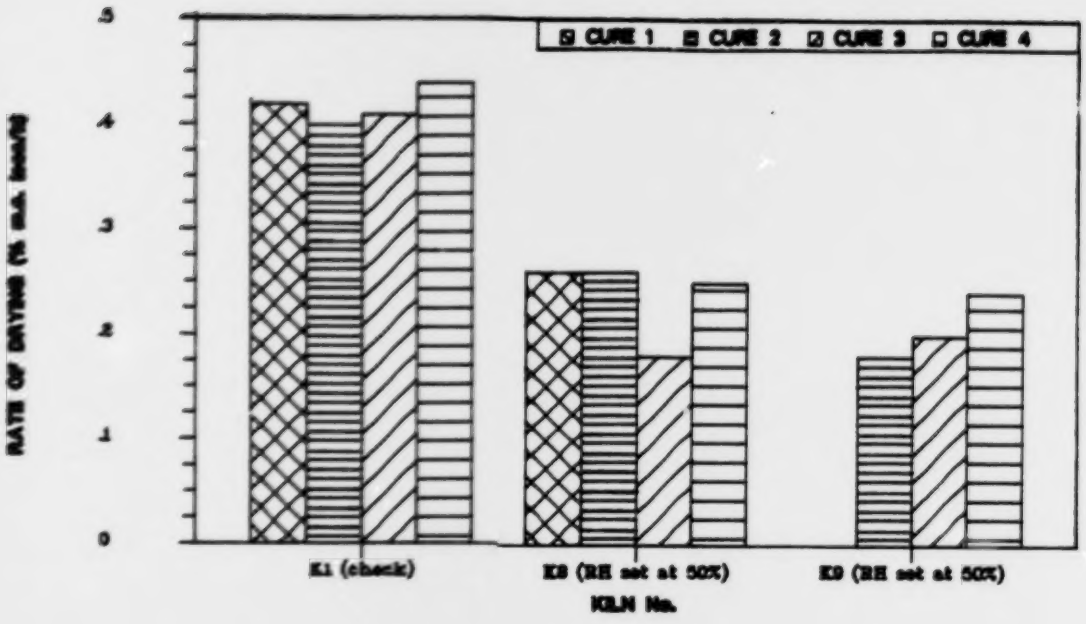

Fig.4P: CURING AIR TEMPERATURES

- Cure 3, Kilns 1, 8, 9 -

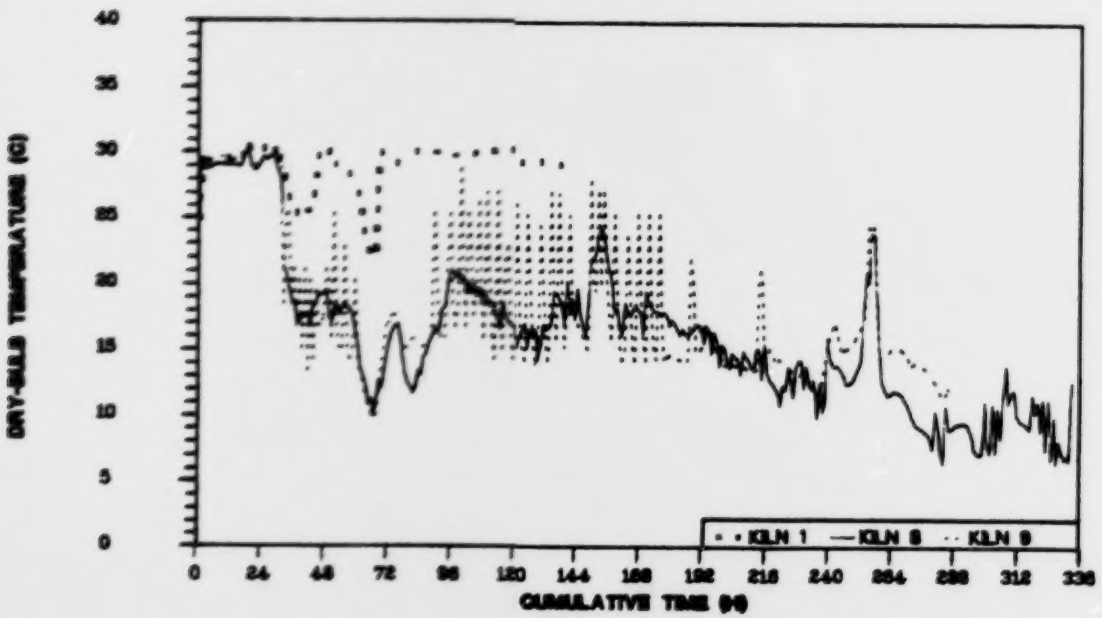

Fig.5P: CURING AIR RELATIVE HUMIDITIES

- Cure 3, Kilns 1, 8, 9 -

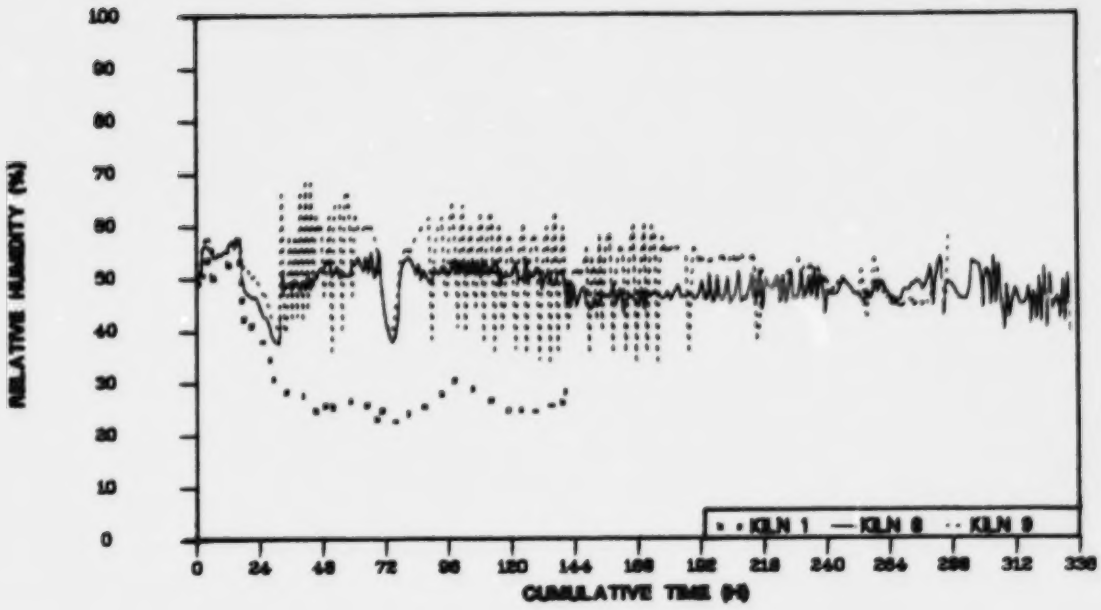

Figure 6P: Panel member evaluation sheet

NAME OF PANEL MEMBER:_____DATE OF TEST/89:_____

SAMPLE:_____

PEANUT NUMBER:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. colour																				
2. peanut flavour score																				
3. off-flavour score																				
COMMENTS:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
4. off-flavours																				
5. roast																				
6. texture																				
7.blanchability																				

TABLE 1P: Air flow rates recorded during peanut curing in 180 rack, "DeCloet", bulk kilns

KILN #	LOADING DEPTH (mm)	VOLUME OF PEANUTS (m^3)	AIR FLOW* (L/s)	AIR FLOW RATE ($L/s/m^3$)
1	470	17.07	4510	264
2	520	18.88	6030	319
3	520	18.88	5170	274
4	550	19.97	5950	298
5	580	21.06	5645	268

*An "Alnor" velometer was used to measure air flow. The velometer covers an area of about 350 mm x 350 mm and measures the velocity with a set of pitot tubes. The meter is calibrated to indicate the result as an air flow rate in cubic feet per minute. The velometer was placed on top of the peanut layer in 5 bulk kilns and the air flow exiting the peanut layer was recorded (converted to L/s).

TABLE 2P: Data resulting from curing peanuts at different air flows

CURE # (date)	KILN #	AIR FLOW RATE (L/s/m²)	MOISTURE CONTENT initial (%w.b.)	MOISTURE CONTENT final (%w.b.)	CURE LENGTH no-recirc. (h)	CURE LENGTH recirc. (h)	CURE LENGTH total (h)	RATE OF DRYING (% m.c./h)
1	1	586	75.35	8.24	65.2	96.1	161.3	0.42
(Sept. 19)	2	475	75.35	9.54	65.2	96.1	161.3	0.41
	3	439	75.35	9.47	65.2	103.6	168.8	0.39
	4	365	75.35	9.96	65.2	103.6	168.8	0.39
	5	350	75.35	8.82	65.2	119.6	184.8	0.36
	6	324	75.35	9.35	72.4	136.4	208.8	0.32
	7	316	75.35	8.70	72.4	120.4	192.8	0.35
2	1	610	66.08	9.21	49.5	92.0	141.5	0.40
(Sept. 29)	2	522	66.08	9.66	49.5	92.0	141.5	0.40
	3	445	66.08	10.20	67.5	80.3	147.8	0.38
	4	380	66.08	9.97	67.5	80.3	147.8	0.38
	5	357	66.08	9.60	75.5	90.3	165.8	0.34
	6	313	66.08	9.48	75.5	96.5	172.0	0.33
	7	319	66.08	9.98	91.0	81.0	172.0	0.33
3	1	602	64.89	9.18	49.0	91.6	140.6	0.40
(Oct. 7)	2	491	64.89	9.85	49.0	91.6	140.6	0.39
	3	456	64.89	8.70	68.0	72.6	140.6	0.40
	4	369	64.89	9.00	68.0	79.1	147.1	0.38
	5	340	64.89	9.84	68.0	72.6	140.6	0.39
	6	336	64.89	9.27	75.8	87.7	163.5	0.34
	7	303	64.89	9.92	75.8	71.3	147.1	0.37
4	1	622	67.84	9.26	67.5	72.5	140.0	0.41
(Oct. 17)	2	527	67.84	9.04	67.5	80.3	147.8	0.40
	3	522	67.84	9.74	67.5	80.3	147.8	0.39
	4	386	67.84	9.84	74.5	73.3	147.8	0.39
	5	337	67.84	9.23	91.8	71.2	163.0	0.36
	6	373	67.84	9.85	91.8	71.2	163.0	0.36
	7	317	67.84	8.90	98.4	64.6	163.0	0.36

TABLE 3P: Debris contained within peanut pods that were cured at different air flows

CURE # (date)	KILN #	AIR FLOW RATE ($L/s/m^3$)	PEANUT POD AND DEBRIS WT. (kg)	DEBRIS WT. (kg)	DEBRIS WT. PER TOTAL POD WT. (%)
1	1	586	29.9	3.6	12.0
(Sept. 19)	2	475	35.1	4.1	11.7
	3	439	41.3	4.8	11.6
	4	365	43.1	5.2	12.1
	5	350	46.5	4.8	10.3
	6	324	50.1	6.4	12.8
	7	316	53.0	7.3	13.8
2	1	610	33.3	2.0	6.0
(Sept. 29)	2	522	39.5	1.8	4.6
	3	445	47.8	3.4	7.1
	4	380	48.1	2.7	5.6
	5	357	51.7	3.6	7.0
	6	313	57.1	3.6	6.3
	7	319	59.2	4.1	6.9
3	1	602	35.4	5.4	15.3
(Oct. 7)	2	491	43.3	6.6	15.2
	3	456	46.0	6.6	14.3
	4	369	50.6	5.7	11.3
	5	340	50.8	3.4	6.7
	6	336	55.8	4.3	7.7
	7	303	63.3	4.3	6.8
4	1	622	35.4	5.2	14.7
(Oct. 17)	2	527	42.9	5.9	13.8
	3	522	45.1	4.1	9.1
	4	386	50.3	4.3	8.5
	5	337	53.5	3.9	7.3
	6	373	59.9	3.2	5.3
	7	317	64.9	4.1	6.3

TABLE 4P: Data resulting from curing peanuts at a controlled curing air relative humidity

CURE # (date)	KILN #	CURING AIR RELATIVE HUMIDITY	MOISTURE CONTENT initial (%w.b.)	MOISTURE CONTENT final (%w.b.)	CURE LENGTH no-recirc. (h)	CURE LENGTH recirc. (h)	CURE LENGTH total (h)	RATE OF DRYING (%m.c./h)
1	1	--	75.35	8.24	65.2	96.1	161.3	0.42
(Sept. 19)	8	controlled	75.35	9.08	65.2	191.6	256.8	0.26
2	1	--	66.08	9.21	49.5	92.0	141.5	0.40
(Sept. 29)	8	controlled	66.08	8.80	69.7	149.0	218.7	0.26
& 30)	9	controlled	66.08	9.77	67.5	248.6	316.1	0.18
3	1	--	67.84	9.26	67.5	72.5	140.0	0.41
(Oct. 17)	8	controlled	67.84	9.56	91.8	240.2	332.0	0.18
	9	controlled	67.84	10.06	74.5	211.0	285.5	0.20
4	1	--	70.90	9.48	66.2	73.3	139.5	0.44
(Oct. 31)	8	controlled	70.90	9.88	73.2	168.3	241.5	0.25
	9	controlled	70.90	9.83	91.0	165.2	256.2	0.24

TABLE 5P: Physical characteristics of peanuts cured at different air flows

CURE # (date)	KILN #	AIR FLOW RATE (L/s/m³)	CLEAN POD WT. (g)	SHELL[1] OUT (%)	TOTAL[2] SMK (%)	OIL[3] (%)	% PICK[4] dis-coloured (%)	mechanical damaged (%)	split (%)	total (%)
1	1	586	911.4	53.8	41.0	12.8	0.2	0.4	0.0	0.6
(Sept. 19)	2	475	1018.7	52.6	42.9	9.7	0.1	0.8	0.2	1.1
	3	439	770.8	54.9	47.4	7.5	0.5	0.9	0.0	1.4
	4	365	1124.9	53.2	43.9	9.3	0.2	0.3	0.1	0.6
	5	350	967.9	55.7	48.2	7.5	0.1	1.5	0.0	1.6
	6	324	805.6	56.8	48.4	8.4	0.3	0.5	0.0	0.8
	7	316	912.1	54.3	45.6	8.7	0.2	0.7	0.0	0.9
2	1	610	1346.2	56.7	46.3	10.4	0.4	1.5	0.1	2.0
(Sept. 29)	2	522	1412.3	57.6	47.4	10.2	0.5	0.9	0.0	1.4
	3	445	1298.5	58.0	48.1	9.9	0.5	1.2	0.1	1.8
	4	380	1169.3	61.2	50.8	10.4	0.6	1.4	0.1	2.1
	5	357	1319.6	57.7	48.0	9.7	1.0	1.0	0.1	2.1
	6	313	1415.9	59.4	50.5	8.9	0.2	2.7	0.2	3.1
	7	319	1351.9	58.7	49.9	8.8	0.3	1.2	0.1	1.6
3	1	602	1121.4	60.6	49.2	11.4	0.2	2.0	0.2	2.4
(Oct. 7)	2	491	1205.3	60.0	48.7	11.3	0.4	3.8	0.2	4.4
	3	456	1188.3	59.1	47.9	11.2	1.2	1.4	0.1	2.7
	4	369	1452.1	61.5	52.0	9.5	1.3	1.2	0.2	2.7
	5	340	1498.8	60.0	49.3	10.7	1.3	1.6	0.1	3.0
	6	336	1273.3	60.4	50.7	9.7	0.9	1.4	0.2	2.5
	7	303	993.5	57.9	48.2	9.7	0.7	1.9	0.2	2.8
4	1	622	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(Oct. 17)	2	527	1243.1	60.6	50.4	10.2	2.4	0.9	0.1	3.4
	3	522	1390.8	62.4	52.2	10.2	2.3	0.6	0.1	3.0
	4	386	1316.4	62.7	52.5	10.2	5.7	1.5	0.3	7.5
	5	337	1387.3	61.5	52.5	9.0	5.5	1.4	0.0	6.9
	6	373	1363.2	60.7	50.3	10.4	7.5	1.5	0.4	9.4
	7	317	1398.6	60.1	49.4	10.7	8.7	1.5	0.3	10.5

[1]Shell Out % -Total weight of kernels expressed as percentage of total clean pod weight.

[2]Total SMK % - Kernels greater than 5.95 mm expressed as percentage of total clean pod weight.

[3]Oil % - Kernels less than 5.95 mm which are suitable for crushing for oil expressed as percentage of total clean pod weight

[4]Pick % - Expressed as a percentage of the total SMK weight.

TABLE 6P: Physical characteristics of peanuts cured at a controlled relative humidity

CURE # (Date)	KILN #	CURING AIR RELATIVE HUMIDITY	CLEAN POD WT. (g)	SHELL[1] OUT (%)	TOTAL[2] SMK (%)	OIL[3] (%)	% PICK[4]			
							dis-coloured (%)	mechanical damage (%)	splits (%)	total (%)
1	1	--	911.4	53.8	41.0	12.8	0.2	0.4	0.0	0.6
(Sept. 19)	8	controlled	899.7	50.7	42.1	8.6	0.5	1.0	0.0	1.5
2	1	--	1346.2	56.7	46.3	10.4	0.4	1.5	0.1	2.0
(Sept. 29)	8	controlled	1163.7	58.7	46.3	12.4	0.6	0.8	0.1	1.5
& 30)	9	controlled	1280.3	58.0	49.0	9.0	0.3	0.8	0.1	1.2
3	1	--	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
(Oct. 17)	8	controlled	1353.7	60.9	51.0	9.9	9.0	1.1	0.1	10.2
	9	controlled	1268.2	60.5	51.3	9.2	1.5	0.9	0.4	2.8
4	1	--	1051.9	60.3	47.1	13.2	20.1	2.4	0.2	22.7
(Oct. 31)	8	controlled	1139.6	61.8	50.8	11.0	26.8	2.0	0.3	29.1
	9	controlled	1187.7	60.3	49.4	10.9	15.7	1.7	0.0	17.4

[1]Shell Out % - Total weight of kernels expressed as percentage of total clean pod weight.

[2]Total SMK % - Kernels greater than 5.95 mm expressed as percentage of total clean pod weight.

[3]Oil % - Kernels less than 5.95 mm which are suitable for crushing for oil expressed as percentage of total clean pod weight.

[4]Pick % - Expressed as a percentage of the total SMK weight.

TABLE 7P: Seed viability of peanuts cured at different air flows

CURE # (date)	KILN #	AIR FLOW RATE ($L/s/m^3$)	GERMINATION (%)
1	1	586	100
(Sept. 19)	2	475	93
	3	439	94
	4	365	93
	5	350	92
	6	324	91
	7	316	93
2	1	610	90
(Sept. 27)	2	522	91
	3	445	87
	4	380	95
	5	357	92
	6	313	97
	7	319	90
3	1	602	77
(Oct. 7)	2	491	82
	3	456	77
	4	369	85
	5	340	95
	6	336	89
	7	303	90
4	1	622	93
(Oct. 17)	2	527	92
	3	522	97
	4	386	88
	5	337	89
	6	373	95
	7	317	96

TABLE 8P: Seed viability of peanuts cured at a controlled relative humidity

CURE # (date)	KILN #	CURING AIR RELATIVE HUMIDITY	GERMINATION (%)
1	1	--	100
(Sept. 19)	8	controlled	97
2	1	--	90
(Sept. 29	8	controlled	97
& 30)	9	controlled	93
3	1	--	93
(Oct. 17)	8	controlled	89
	9	controlled	97
4	1	--	46
(Oct. 31)	8	controlled	42
	9	controlled	62

TABLE 9P: Appearance and flavour scores for peanuts cured at different air flows

CURE # (date)	KILN #	AIR FLOW RATE ($L/s/m^3$)	PANEL RATING	
			APPEARANCE (max. score 100)	FLAVOUR (max. score 100)
1	1	586	90.8	66.0
(Sept. 19)	2	475	91.0	61.2
	3	439	89.2	53.6
	4	365	92.5	61.0
	5	350	90.7	65.5
	6	324	94.3	71.7
	7	316	94.7	67.1
2	1	610	95.2	69.1
(Sept. 29)	2	522	98.2	71.5
	3	445	96.8	71.7
	4	380	96.7	68.2
	5	357	96.8	73.4
	6	313	99.7	71.5
	7	319	99.3	71.9
3	1	602	95.8	70.9
(Oct. 7)	2	491	96.3	69.9
	3	456	94.3	70.3
	4	369	94.3	71.4
	5	340	93.0	70.6
	6	336	96.0	74.1
	7	303	96.0	71.8
4	1	622	92.7	72.7
(Oct. 17)	2	527	94.0	70.3
	3	522	94.8	69.8
	4	386	95.7	67.3
	5	337	95.5	73.5
	6	373	94.3	66.2
	7	317	93.8	70.4

TABLE 10P: Appearance and flavour scores for peanuts cured at a controlled relative humidity

CURE # (date)	KILN #	CURING AIR RELATIVE HUMIDITY	PLANEL RATING	
			APPEARANCE (max. score 100)	FLAVOUR (max. score 100)
1	1	--	90.8	66.0
(Sept. 19)	8	controlled	90.8	64.5
2	1	--	95.2	69.1
(Sept. 29	8	controlled	99.3	70.6
& 30)	9	controlled	97.7	75.1
3	1	--	92.7	72.7
(Oct. 17)	8	controlled	95.7	72.2
	9	controlled	93.8	66.3
4	1	--	75.2	55.0
(Oct. 31)	8	controlled	72.2	51.3
	9	controlled	71.8	53.8

TABLE 11P: Fuel energy consumption for peanuts cured at different air flows

CURE # (date)	KILN #	AIR FLOW RATE ($L/s/m^3$)	FUEL USEAGE (kWh)	H_2O REMOVED (kg)	FUEL ENERGY PER H_2O REMOVED (MJ/kg)
1	1	586	132	71.6	6.6
(Sept. 19)	2	475	126	82.8	5.5
	3	439	125	97.6	4.6
	4	365	135	100.5	4.8
	5	350	155	112.6	5.0
	6	324	138	117.0	4.2
	7	316	145	123.6	4.2
2	1	610	118	52.5	8.1
(Sept. 29)	2	522	120	62.7	6.9
	3	445	117	73.1	5.8
	4	380	128	75.1	6.1
	5	357	157	80.1	7.1
	6	313	160	89.3	6.5
	7	319	174	91.1	6.9
3	1	602	179	47.6	13.5
(Oct. 7)	2	491	183	57.5	11.5
	3	456	197	63.1	11.2
	4	369	208	71.5	10.5
	5	340	219	74.3	10.6
	6	336	231	81.6	10.2
	7	303	226	92.4	8.8
4	1	622	196	55.0	12.8
(Oct. 17)	2	527	198	67.6	10.5
	3	522	172	74.1	8.4
	4	386	205	83.0	8.9
	5	336	255	90.4	10.2
	6	373	241	102.2	8.5
	7	317	255	111.4	8.2

TABLE 12P: Fuel energy consumption for peanuts cured at a controlled relative humidity

CURE # (date)	KILN #	CURING AIR RELATIVE HUMIDITY	FUEL USEAGE (kWh)	H_2O REMOVED (kg)	FUEL ENERGY PER H_2O Removed (MJ/kg)
1	1	--	132	51.6	9.2
(Sept. 19)	8	controlled	85	80.4	3.8
2	1	--	118	52.5	8.1
(Sept. 29	8	controlled	156	57.1	9.8
& 30)	9	controlled	101	67.7	5.4
3	1	--	196	55.0	12.8
(Oct. 17)	8	controlled	107	71.2	5.4
	9	controlled	83	71.1	4.2
4	1	--	198	66.9	10.7
(Oct. 31)	8	controlled	157	73.6	7.7
	9	controlled	199	72.4	9.9

ii) POPCORN DRYING IN BULK TOBACCO KILNS

BACKGROUND

The bursting of popcorn kernels occurs at a temperature between 177° and 270°C. Heat causes the moisture inside of a popcorn kernel to turn to steam which exerts pressure on the hard seed coat of the kernel. When a high enough pressure is exerted, the kernel explodes.

Popcorn quality is determined by its popping volume. This is the volume of popped flakes produced from a weight of unpopped kernels. Popcorn kernels pop at a moisture content between 8 and 16% (w.b.), however, the best popping volume is attained at a moisture content between 13.0 and 14.5% (w.b.). The optimum moisture content for maximum popping volume is 13.5% (Ziegler 1984).

Rapid drying or rehydrating of popcorn reduces popping volume. Stress cracks develop in the kernel which weaken the seed coat and when the kernel is heated the cracks allow some of the steam pressure to escape prior to popping. The expansion volume is reduced because the steam pressure exerted on the seed coat is reduced. Thus, the popping volume or quality of popcorn is highly dependent on the drying procedure used.

High temperature air drying is not recommended for popcorn. Overdrying, non-uniform drying and too rapid drying result from high temperature air drying. The maximum drying air temperature for popcorn is 49°C. A more acceptable air temperature range is 32° to 38°C (Ziegler, 1984). Drying popcorn at a high air temperature would only be used to increase the drying rate to prevent spoilage.

If high air temperatures must be used, the quality of the popcorn can be improved by drying in stages. The first stage involves using heated air until the moisture content of the popcorn is between 17 and 18% (w.b.). The next stage is to use natural air or low temperature air drying until the moisture content of the popcorn is 13.5% (w.b.). An alternative to this method is to use 12 to 24 hour periods of tempering throughout the high air temperature drying process. This allows for moisture redistribution within the popcorn kernels.

Natural air drying of popcorn, at less than 18% moisture content (w.b.), requires an air flow no less than 33 L/s per tonne of popcorn. Ambient air less than 60% relative humidity requires no additional heat for drying.

Heat is required only when the ambient air is greater than 80% relative humidity. A 3.5 to 5.0°C increase of the ambient air temperature is recommended when the ambient air relative humidity is greater than 80% (Ziegler, 1984). A humidistat is often used to automate the cycling of the heater. When the relative humdity of the ambient air is less than 60% the heater is cycled off and when its above 80% the heater is cycled on. Heater cycling prevents stress cracking of popcorn kernels from too fast a drying rate.

In cooperation with a popcorn grower, Odiel Masschaele, Delhi, a project was intiated to investigate drying shelled popcorn in bulk tobacco kilns.

OBJECTIVE

The objective of the project was to determine if popcorn can be successfully dried in bulk kilns.

The following were investigated:

a) bulk kiln modifications;

b) handling methods;

c) drying method and its effects on popcorn;

d) and energy requirements.

METHOD

Kiln Specifications

The popcorn was dried in a "DeCloet", 15 bin, bulk tobacco kiln. Inside floor dimensions of the curing compartment of the bulk kiln are 10780 mm (length) x 3070 mm (width). Height of the sidewalls of the curing compartment is 2440 mm (measured from the perforated floor to the eave of the kiln).

The furnace unit of the kiln is equipped with a centrifugal blower powered by a 5.6 kW single phase motor. Air flow produced by the blower is 7200 L/s @ 470 Pa (kiln manufacturer's rating).

The burner unit of the kiln is direct-fired and fuelled by natural gas. The fuel energy input of the burner is rated at 411 MJ/h.

The kiln is insulated in the roof and sidewalls with 25 mm thick expanded polystyrene and 75 mm thick fibreglass, respectively.

Kiln Modifications

Operation of the kiln's blower and burner and the air circulation pattern

within the curing compartment were not altered. The only modification undertaken was the removal of the ambient air intake vent on the front of the furnace unit. The vent was removed to allow as much ambient air as possible to mix with air that was recirculating through the popcorn in the bulk kiln during drying. Introducing ambient air into the bulk kiln also pressurized the curing compartment and forced a portion of the moisture-laden air circulating within the curing compartment to be expelled through exhaust louvres located above the doors at the loading end of the kiln.

Handling Methods

Small-sized, yellow, popcorn was harvested with a combine equipped with a corn head and transported to the bulk kiln in a grain wagon. The popcorn was then loaded into the bulk kiln using a belt conveyor and distributed manually on the perforated floor to a uniform depth. After drying was completed the popcorn was shovelled into bags and stored in a barn until marketing.

Blower/Burner Operation

The blower and burner were turned on immediately after loading was completed. The thermostat of the burner was set at 17°C. The burner was turned off twice during the drying process: the first burner off period allowed for moisture redistribution within the kernels and the second burner off period was for completing the drying process using natural air. The blower was turned off after drying was completed.

MONITORING

Monitoring procedures were as follows:

1.) Initial and final moisture contents of the popcorn were determined using an oven-dry method of 106°C for 72 hours and a "Dickey John Grain Computer", respectively;

2.) Type K thermocouples and a "Kaye-Digi III" datalogger were used to record hourly temperatures and relative humidities of the ambient air, drying air and air exiting the top of the popcorn layer;

3.) An "Alnor" air velometer was used to record air flow through the popcorn and through the ambient air intake vent on the furnace.

4.) A natural gas meter and volt-amp meter were used to record drying energy useage.

RESULTS AND EVALUATION

Drying Summary

Popcorn was loaded into the bulk kiln at a moisture content of 29.40% (w.b.). The entire area of the perforated floor of the curing compartment was filled with popcorn kernels to a uniform depth of 305 mm. Total volume of popcorn in the bulk kiln was 10.09 m^3.

The blower of the furnace unit operated during the entire drying period for 165.5 h. Figure 1Po illustrates the hourly average dry-bulb temperature and relative humidity of the drying air during the drying period.

Heat was not added to the drying air during two stages - between the 42nd and 55th hours and between the 115th and 166th hours of drying. During these stages the majority of air within the kiln was recirculated while a small amount of ambient air was added to the air recirculating in the bulk kiln. During the time the burner was on the temperature of the drying air was usually maintained between 17 and 17.5°C. The relative humidity of the drying air was always maintained above 60%.

After completion of drying the moisture content of the popcorn kernels averaged 13.73% (w.b.). The moisture content difference between the bottom and top of the popcorn layer was 0.06%. The closeness of the moisture contents between the top and bottom of the layer can probably be attributed to recirculating the drying air with no heat during the latter stage of drying.

The depth of the popcorn layer after completion of drying was 242 mm. Thus, shrinkage of the popcorn layer was about 20%. The dried popcorn was estimated to weigh 6.60548 t at a moisture content of 13.73% (w.b.).

Air Flow

Air flow measurements were recorded during the first day of drying. Air flow through the popcorn was measured to be 625 L/s/m^3 of popcorn. Air flow through the ambient air vent opening on the furnace unit was measured to be 405 L/s. It can be assumed that since the ambient air introduced in the bulk kiln created a positive pressure within the curing compartment, the amount of air exiting the exhaust louvres above the doors at the loading end of the bulk kiln was equal to or less than the ambient air introduced into the curing compartment. Thus, at least 5900 L/s of air was returning to the furnace unit after it had passed through the popcorn.

Energy Consumption

Natural gas consumption during drying was 99.12 m^3 while electrical consumption was 608 kWh*. Since the final moisture content of the 6.60548 t of dried popcorn was 13.73% (w.b.) and its initial moisture content was 29.40% (w.b.), about 1466 kg of water was removed during drying. Thus, the total energy consumed per kilogram of water removed was 4.04 megajoules.

Based on 1988 energy prices of $0.175 per m^3 of natural gas and $0.0567 per kWh of electricity, drying costs total $7.84 per tonne of dried popcorn (@ moisture content of 13.73% w.b.).

*Energy values - natural gas 37.7 MJ/m^3, electricity 3.6 MJ/kWh.

Quality

The quality of the popcorn dried in the bulk kiln was evaluated for its popping volume and compared to the popping volume of a popular name brand popcorn sold at stores across the continent. Both types of popcorn were popped in a hot air popper under similar test conditions. Five samples of each type of popcorn were weighed, popped, and then evaluated for volume (cc) of popped flakes in relation to the initial weight (g) of the unpopped kernels.

Table 1Po shows the results from the popping volume test. The popping volume averaged 28.50 cc/g for the popcorn dried in the bulk kilns and 29.83 cc/g for the name brand popcorn. Thus, the popping volume of the name brand popcorn was 4.4% larger than the popcorn that was dried in the bulk kiln.

Based on the test results, it would appear that the popcorn dried in the bulk kiln competed reasonably well against the name brand popcorn. It can be assumed that the drying technique used to dry the popcorn in the bulk kiln did not adversely affect its popping volume.

CONCLUSIONS

1.) Popcorn can be dried in bulk kilns provided that low temperature and controlled relative humidity air is used.

2.) Natural gas and electrical energy consumed to dry popcorn in a bulk kiln totalled 4.04 megajoules per kg of water removed.

3.) Based on 1988 energy prices, natural gas and electrical costs totalled

$7.84 per tonne of popcorn that was dried from an initial moisture content of 29.40% (w.b.) to a final moisture content of 13.73% (w.b.).

4.) The popping volume of popcorn dried in the bulk kiln compared reasonably well against a name brand popcorn.

RECOMMENDATIONS

If the cooperator grows popcorn in 1989 and uses a bulk kiln to dry the popcorn, more data should be collected to verify results from the 1988 year.

LITERATURE CITED

Ziegler, K. E. et. al. 1984. Popcorn production and marketing. National corn handbook NCH-5. Purdue University, Indiana. 6pp

Fig.1Pe: POPCORN DRYING HISTORY

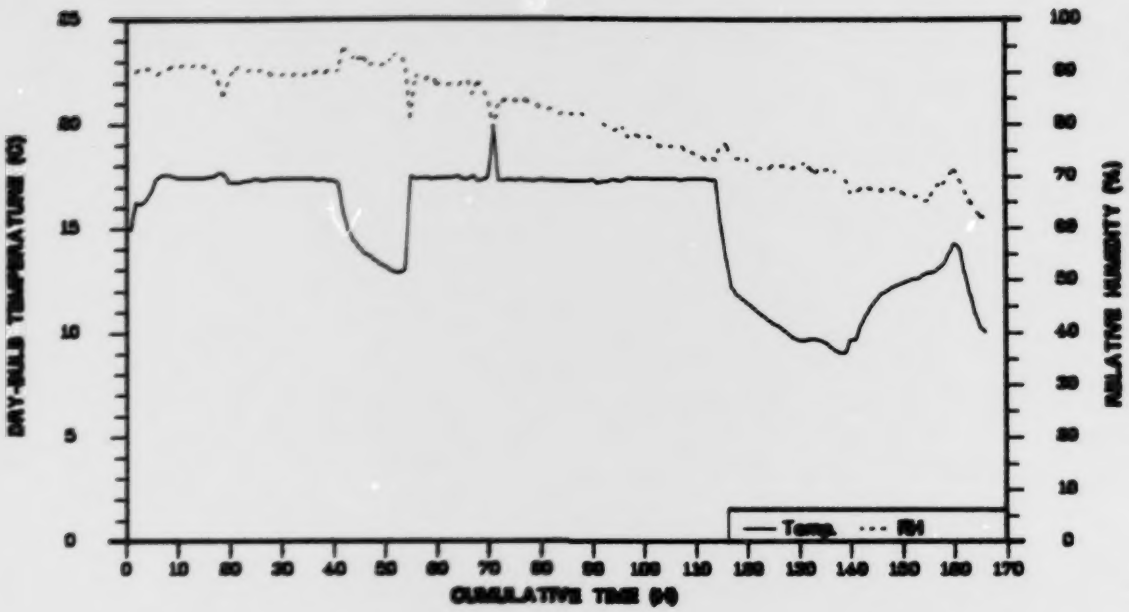

Table 1Po: Popcorn Popping Evaluation

SAMPLE (#)	KILN DRIED POPCORN (cc/g*)	NAME BRAND POPCORN (cc/g)
1	27.46	26.35
2	27.99	29.21
3	27.71	32.13
4	30.13	31.00
5	29.19	30.44
AVG.	28.50	29.83

*cubic centimetres (cc) of popped flakes per gram (g) of unpopped popcorn kernels.

iii) CURING SPANISH ONIONS IN BULK TOBACCO KILNS

BACKGROUND

In 1988, the Agricultural Energy Centre examined the effects of curing spanish onions in tobacco kilns located at the Agriculture Canada Research Station, Delhi, Ontario. The project was conducted in cooperation with Jerry Omstead, Omstead Foods Limited, Wheatley, Ontario.

Artificial curing of spanish onions is necessary when wet field conditions exist at harvest so that the incidence of "neck rot" is reduced during storage (Jarvis, 1983). Even though harvest conditions in 1988 were dry, the primary objective of the project was to determine if bulk kilns can be utilized to cure different varieties of spanish onions. If successful, Omstead Foods Limited would then transfer the spanish onions to a storage facility and evaluate the response of different varieties of spanish onions in relation to storage longevity.

Curing guidelines followed for the project were as follows: air dry-bulb temperature between 24 and 27°C; air relative humidity between 60 and 75%; and a minimum air flow rate of 80 L/s/m^3 of spanish onions (Tiessen et al, 1981).

The quality of the cured spanish onions was evaluated on appearance and firmness of the bulbs and texture of the neck. Weight loss, also an indication of cured quality, was recorded for each variety of spanish onions.

METHOD

Kiln Specifications

Two different types of kilns were used to cure the spanish onions: a "Unimatic" bulk kiln and a small-scaled bulk kiln that is normally used to cure small quanities of tobacco.

The "Unimatic" is usually referred to as a 162 rack, 3 bay type, bulk kiln. Inside dimensions of the floor area of the curing compartment are 7150 mm (length) x 4660 mm (width). The height of the curing compartment is 2290 mm (measured from perforated floor to eave). The kiln is equipped with a "Duo-Matic Model #CFG-508" furnace unit. The direct-fired burner of the furnace unit is fuelled by natural gas. Specifications on the air flow output of the furnace unit's axial flow fan are unavailable.

Researchers at the Research Station have modified the air flow distribution in the "Unimatic" kiln so that small quanities of crops can be cured in 4 sections (of equal size) in each of the outer bays of the

kiln. The perforated floor in the middle bay of the kiln was removed and a plywood duct, extending from the outlet of the fan to the loading end of the kiln, was installed in the open space that had been below the perforated floor. Openings cut into the sidewalls of the duct serve as the air source for each curing section of the kiln. Plywood gates control the amount of air that goes into the plenum below the perforated floor of each curing section. Plywood walls separate each curing section and extend from the lower plenum below the perforated floor up 900 mm above the perforated floor (as shown in Figure 1So).

The small-scaled bulk kiln or "test" kiln has a capacity of 9 racks when used for tobacco. The dimensions of the perforated floor area of the curing compartment are 1230 mm (length) x 1510 mm (width). The height of the sidewalls of the curing compartment are 2200 mm (measured from the perforated floor to the eave of the kiln). The kiln is equipped with a "Clare Brothers Model #GDF 120" furnace unit. The centrifugal blower of the furnace unit is a "Delhi Industries Model G-10" and is belt driven by a 0.7 kW electric motor. The indirect-fired burner of the furnace unit is fuelled by natural gas and rated at 137 MJ/h.

No structural modifications were undertaken to either kiln. There was no need to use a full-sized bulk tobacco kiln since only small quanities of different varieties of spanish onions were to be cured.

Loading Procedure

The "Unimatic" kiln was loaded with different varieties of spanish onions, delivered in open-mesh style bags, on two dates: 643.7 kg of Vega and Yula varieties on August 22; and 680.3 kg of Autumn Surprise, Vega and Yula varieties on August 26. The bags of onions were placed on the perforated floors in four curing sections in the kiln. The bags were stacked three high or about 460 mm deep in each curing section. Air flow gates were adjusted so that curing sections not used received no air while the loaded curing sections received at least 80 L/s of air per cubic metre of spanish onions. Curing was completed on September 9 for both loading dates.

Bags of the Vega variety were also loaded into the "test" kiln on August 26. The bags were emptied into a 1220 mm x 1220 mm x 635 mm (high) tote

box, with an open-mesh steel floor, positioned on the perforated floor in the curing compartment of the test kiln. Weight of the spanish onions loaded was 237.6 kg. Curing was also completed on September 9.

It should be noted that to properly cure the spanish onions in the tote box, the open space between the outer perimeter of the tote box and the walls of the curing compartment was sealed with polyethylene to prevent air channelling.

Curing Procedure

Intentions were to cure the spanish onions in the two kilns using a minimum air flow rate of 80 L/s per cubic metre of spanish onions with an air dry-bulb temperature between 24 and 27°C at a relative humidity of 60 to 75%.

The thermostat of each kiln was set at 24°C. Since only a small volume of spanish onions was being cured in each kiln and would release very little moisture, the ambient air vents on the furnace units of the kilns were kept closed. This allowed the curing air relative humidity to stay reasonably high to prevent the spanish onions from dehydrating.

Monitoring

1.) The weight of each variety of spanish onions prior to and after curing was measured to determine the % weight loss resulting from curing.
2.) Dry-bulb temperature and relative humidity of the curing air in each kiln were recorded with a thermohygrograph.
3.) Air flow through the spanish onions was measured in both kilns using an "Alnor" velometer during the initial days of curing.
4.) The spanish onions were observed routinely throughout the curing period to determine when curing was complete. This was indicated by the appearance of the outer layer of skin on the bulbs and dryness of its neck.

RESULTS AND EVALUATION

In the "Unimatic" kiln an average curing air dry-bulb temperature of 26.7°C at 47% relative humidity was recorded for spanish onions cured from August 22 to September 9. An average curing air dry-bulb temperature of 26.6°C at 48% relative humidity was recorded for spanish onions cured from August 26 to September 9. Air flow, recorded during the initial days of

curing for both loading dates, averaged 190 L/s per cubic metre of spanish onions.

The average curing air conditions are deceiving. Mechanical problems encountered with the burner of the "Unimatic" kiln resulted in a wide fluctuation in air temperature and relative humidity throughout most of the curing period. The air dry-bulb temperature ranged from ambient air temperature to 40°C whereas the relative humidity ranged from 14% to 8[illegible]%.

Table 1So indicates the weight loss recorded from curing the different varieties of spanish onions in the "Unimatic" kiln. The weight loss ranged from 1.86 to 2.84%.

Optimum curing air conditions were also not attained in the "test" kiln. An average air flow rate of 290 L/s/m^3 of spanish onions was measured during the initial days of curing. This is considerably greater than the recommended minimum air flow rate of 80 L/s/m^3 of spanish onions. The high air flow rate in conjunction with an over-sized burner and a small quanity of spanish onions cured resulted in an average curing dry-bulb air temperature of 28.2°C at 46% relative humidity. As indicated in Table 1So, a weight loss of 2.48% resulted from curing the Vega variety of spanish onions in the "test" kiln.

The different varieties of spanish onions cured in the kilns were evaluated for quality. The skins of the bulbs of the majority of spanish onion varieties cured were brownish-yellow in appearance and could be easily removed from the bulbs. The bulbs were also very firm and the necks were dry with only a few exhibiting "neck rot". The quality of the cured spanish onions, based on visual observations, did not appear to be affected by the curing air conditions that occurred in both kilns.

CONCLUSIONS

1.) Spanish onions were cured successfully in bags and in a tote box in bulk tobacco kilns adapted to cure crops in small quanities.

2.) Spanish onions were cured successfully with a wide range of air dry-bulb temperatures and relative humidities.

RECOMMENDATIONS

The results of the project should not be interpreted to indicate that large quanities of spanish onions can be cured successfully in full-size

bulk tobacco kilns. The results only indicate that small quanities of spanish onions were cured successfully in bulk kilns adapted to cure small quanities of crops for research purposes.

Recommendations are that the project continue another year at the Research Station, Delhi, so that more data can be collected. If the results are again positive, the project should be transfered to a farm site to evaluate the effects of curing large quanities of spanish onions in full-size bulk kilns.

LITERATURE CITED

Jarvis, W. R. 1983. Onion neck rot. Factsheet. Agdex 258/635. Ontario Ministry of Agriculture and Food, Toronto, Ontario.

Tiessen, H., I. L. Nonnecke and M. Valk. 1981. Onions. Publication 486. Agdex 258/20. Ontario Ministry of Agriculture and Food, Toronto, Ontario. pp25.

Figure 1So: Curing sections in "Unimatic" kiln

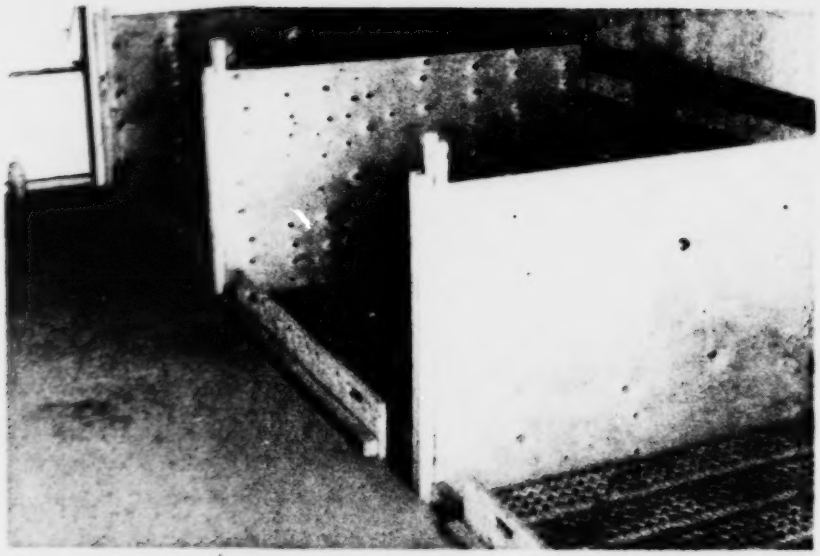

TABLE 1So: Spanish Onion Curing Summary 1988

VARIETY	CURING STRUCTURE	METHOD	GREEN WT. (kg)	CURED WT. (kg)	% WT. Loss	CURE LENGTH h	(days)
VEGA	"Unimatic" Kiln	Bags	282.7	276.4	2.23	424.0	(17.7)
VEGA	"Unimatic" Kiln	Bags	20.1	19.7	2.00	330.0	(13.8)
YULA	"Unimatic" Kiln	Bags	361.0	354.3	1.86	424.0	(17.7)
YULA	"Unimatic" Kiln	Bags	155.4	151.5	2.51	330.0	(13.8)
AUTUMN SURPRISE	"Unimatic" Kiln	Bags	325.3	316.6	2.67	330.0	(13.8)
AUTUMN SURPRISE	"Unimatic" Kiln	Bags	179.5	174.4	2.84	330.0	(13.8)
VEGA	"Test" Kiln	Tote	237.6	231.7	2.48	328.5	(13.7)

iv) GINSENG DRYING IN BULK TOBACCO KILNS

BACKGROUND

In 1988 about 80 ha of cultivated American ginseng roots were harvested in Ontario. These roots were mechanically dried in either specialized dryers or bulk tobacco kilns. The latter is a relatively new concept used by some ginseng growers. No publications are available on "how to" dry ginseng roots in bulk kilns. Drying is usually conducted on a trial and error basis. This is a very risky undertaking since improper drying could significantly reduce the market value of the ginseng.

Ginseng roots are traditionally dried in specialized dryers. The roots are usually spread over lattice or screen-bottom trays which are then placed in the dryer and aerated with relatively low temperature air until the roots are dry. Growers determine the completion of drying by observing how the roots snap when broken by hand.

There are two drying air temperature regimes identified for ginseng drying: 1.) an initial dry-bulb temperature between 15 and 27°C that is slowly increased during drying to a final dry-bulb temperature of 32°C; and 2.) an initial dry-bulb temperature between 38 and 43°C that is decreased to 32°C after the roots have wilted (Williams and Duke, 1978). Unfortunately, the drying regimes identified do not indicate specific relative humidity and air flow rates for the various dry-bulb air temperatures.

During the fall of 1988, two farm operations that dry ginseng in bulk tobacco kilns were monitored to acquire more information about the drying regime. Betty and Fergie Mels, Harley (referred to as site 1 hereafter) and Bob Kozak, Vanessa (referred to as site 2 hereafter), both of whom are ginseng growers, cooperated in the project with the Agricultural Energy Centre.

OBJECTIVES

The overall objective of the project was to determine the technique used to dry ginseng in bulk tobacco kilns at sites 1 and 2.

The investigation included:

1.) air dry-bulb temperatures and relative humidities used during the drying process;

2.) useage and cost of energy for drying;

3.) and quality of dried ginseng roots.

METHOD

Kiln Specifications

Site 1: Ginseng roots were dried in a "Powell" 177 rack, 3 curing compartment, bulk kiln. Inside dimensions of the loading area of the 2 outside curing compartments are 8535 mm (length) x 1500 mm (width). Inside dimensions of the middle curing compartment are 6860 mm (length) x 1500 mm (width). Height of each curing compartment is 2210 mm (measured from perforated floor to eave of kiln).

The furnace unit of the kiln is equipped with a centrifugal blower powered by a 5.6 kW, single phase motor. Air flow that can be produced by the blower is 7000 L/s @ 370 Pa (kiln manufacturer's rating).

The burner is direct-fired and fuelled by propane. The fuel energy input to the burner is rated at 295 MJ/h.

Site 2: Ginseng roots were dried in two identical "DeCloet" , 162 rack, 2 curing compartment, bulk kilns. Inside dimensions of the loading area of each kiln's curing compartment are 10975 mm (length) x 1500 mm (width). Height of each kiln's curing compartment is 2400 mm (measured from the perforated floor to eave of kiln).

The furnace unit of each kiln is equipped with a "Delhi Industries, Model 925" centrifugal blower powered by a 5.6 kW, single phase motor. Air flow that can be produced by the blower is 7200 L/s @ 470 Pa (kiln manufacturer's rating).

The burner of each kiln is direct-fired and fuelled by natural gas. The fuel energy input of each burner is rated at 411 MJ/h.

Each kiln is insulated in the roof and sidewalls with 25 mm thick expanded polystyrene and 75 mm thick fibreglass, respectively.

Kiln Modifications

Site 1: Operation of the kiln's blower, burner and air circulation pattern was not altered, however, modifications were undertaken to facilitate drying the ginseng roots in trays in the bulk kiln.

Trays, constructed of wood frames and screen bottoms, were used to contain the ginseng roots. Dimensions of each tray are 710 mm (length) x 1420 mm (width) x 90 mm (depth).

As illustrated in Figure 1G, each curing compartment was modified so that 9 layers of trays could be dried. The bottom layer of trays is 635 mm above the perforated floor. Each successive layer is separated by a distance of 180 mm. Eleven trays can be dried on each layer in the outer curing compartments while 9 trays can be dried per layer in the middle compartment.

Since drying air circulation in a "Powell" bulk kiln is from the lower to upper plenum, drying air passes through the screen bottoms of the first layer of trays, up through the ginseng roots and on to the next layer. After the drying has passed through the top layer of trays, the majority of it returns to the furnace unit, however, some of it will be expelled out exhaust louvres located above the loading doors. The amount of air exhausted is dependent on the amount of ambient air that is being introduced through the fresh air intake vent on the furnace unit.

Site 2: The operation of the kiln's blower, burner and air circulation pattern were also not modified, but similar to site 1, modifications were undertaken to facilitate drying the ginseng roots in trays in the tobacco kilns.

Trays constructed of wood frames and screen bottoms were also used to contain the ginseng roots. Two tray sizes were used: 1.) 1155 mm (length) x 1180 mm (width) x 70 mm (depth) and 2.) 890 mm (length) x 1180 mm (width) x 70 mm (depth).

As illustrated in Figure 2G, the trays that are 1155 mm long were placed in racks. Each rack holds a total of 26 trays on 13 layers with each layer spaced 150 mm apart. The bulk kilns hold 8 racks each (4 racks in each curing compartment). After the racks have been rolled into the kiln and butted tightly together, the 890 mm long trays are used to fill the remaining floor space of the kiln (see Figure 3G). In each curing compartment 13 trays are stacked vertically and spaced at 90 mm intervals.

Air movement in a "DeCloet" bulk kiln is the same as in a "Powell" kiln. Thus, the drying air passes through the screen bottom of the first layer of trays, then through the ginseng roots and thereafter through each successive layer of trays. Air recirculation and exhausting are similar to that described for the "Powell" bulk kiln at site 1.

Preparation of Ginseng Roots Prior to Drying

At both sites, the ginseng roots were three years old when dug. After digging, the roots were kept in cold storage for about one week. Afterwards, the roots were washed and graded to remove any rotten roots. The roots were then distributed uniformily in the drying trays.

Furnace Operation

At both sites the blower and burner of each kiln were started immediately once all of the trays of ginseng had been loaded into the kiln. Various combinations of air dry-bulb temperatures and relative humidities were used during the drying process at both sites. Drying was considered finished at both sites by the growers. This was determined by observing how the roots snapped when broken. The blower and burner of each kiln remained on until after all of the dried ginseng was unloaded from the kiln.

MONITORING

Monitoring procedures were similar for sites 1 and 2 and are as follows:

1.) Ginseng roots were sampled for moisture content (% w.b.) analyses at various intervals. Samples were taken during loading, drying and after completion of drying. Moisture content was determined using a freeze dryer.

2.) Thermocouples, digital temperature indicators, and Mason's hygrometers were used to determine (randomly) dry-and wet-bulb temperatures of ambient air and drying air within the bulk kilns.

3.) Propane and natural gas meters were used to record fuel consumption. Farm service kWh meters and a volt-amp meter were used to record electrical consumption.

4.) An air velometer was used to record air flow prior to drying. This was done to determine if the measured air flow was similar to that specified by the kiln manufacturer. At both sites the manufacturer's air flow rating was similar to that measured.

RESULTS AND EVALUATION

Drying Summary

At site 1, one load of ginseng roots was dried in the bulk kiln, while at site 2 each bulk kiln dried two loads of ginseng roots. Table 1G summarizes the drying data collected at both sites.

The initial moisture content of the ginseng roots ranged from 68.85 to 71.81% (w.b.). The moisture content of the dried ginseng roots ranged from 5.20 to 7.66% (w.b.). The dried mass of ginseng roots per bulk kiln ranged from 1125 to 1408 kg. The drying period ranged from 14.4 to 17.0 days per bulk kiln.

Drying Air Temperatures and Relative Humidities

Figures 4G to 8G show the air dry-bulb temperatures and relative humidities recorded (randomly) during ginseng drying in the bulk kilns at both sites.

At site 1, the drying period lasted 345 h. The air dry-bulb temperature was increased slowly from about 25°C at about 80% relative humidity during the initial stage of drying to about 39°C at 10 to 13% relative humidity during the latter stage of drying. It should be noted that the relative humidity of the drying air was dropped quickly after about 38.0 h of drying.

After drying was completed, at 284 h, the blower and burner remained on until all of the ginseng roots had been unloaded from the bulk kiln. During the unloading period, which lasted 61 h, the air dry-bulb temperature was decreased to 25°C and was at a relative humidity between 17 and 23%.

At site 2, the length of time to dry each load of ginseng roots ranged from 377 to 408 h. The air dry-bulb temperature ranged from 23 to 27°C at relative humidities between 54 and 71% during the initial stage of drying for the 4 loads of ginseng roots. Air dry-bulb temperature was then slowly increased to between 37 and 38°C, whereas the air relative humidity was dropped quickly after the first 48 h of drying to between 15 and 30% until drying was finished. Similar to site 1, the blower and burner of each bulk kiln remained on until all of the ginseng roots had been removed from the bulk kilns. During this period, the air dry-bulb temperature was about 30°C at relative humidities between 20 and 30%.

Moisture Loss of Ginseng Roots During Drying

Figures 9G to 13G show the moisture loss of the ginseng roots during drying at sites 1 and 2. Sampling for moisture content analyses was done in a random fashion from trays nearest the loading end of the kilns. This method of sampling probably resulted in some error and could be responsible for the occasional increase in moisture content during drying.

Energy Consumption

Table 2G summarizes the energy required to dry the ginseng roots at both sites. The amount of water removed from the ginseng roots ranged between 2381 and 3133 kg per load of ginseng roots dried. Total energy useage per kg of water removed ranged from 11.36 to 15.61 MJ/kg per load of ginseng roots.

Table 3G indicates the fuel and electrical costs to dry the ginseng roots at site 1 and 2. The total energy cost for drying at site 1 was $0.28 per kg of dried ginseng (@ 5.83% m.c.). This is considerably more than the total energy cost for drying at site 2. This can be attributed to the higher cost per heating value for propane as compared to natural gas. The total energy cost for drying at site 2 ranged between $0.17 and $0.19 per kg of dried ginseng roots (@ 7.66% and 6.54 % m.c., respectively).

Quality of Dried Ginseng Roots

Both growers were very satisfied with the dried appearance of their ginseng roots. The roots had a consistent creamish-yellow appearance with no traces of a green colour. The interior of the roots was slightly off-white and considered acceptable.

Ginseng roots that have a green appearance will sell for much less than roots with a creamish-yellow appearance. Both growers purposely maintained drying air temperatures at about 38°C during the latter stages of drying to prevent the roots from fixing a green colour. The growers were basing the drying air temperature on research conducted at the University of Minnesota. Li and Morey, 1987, concluded that the green colour occurs when the drying air temperature is 27°C and the moisture content of the ginseng roots are 28 to 30% (w.b.) or less. They found that drying at 38°C, when the ginseng roots are 28 to 30% (w.b.) moisture content or less, eliminates development of green colour and also prevents an undesirable brown colour.

The grower at site 2, monitored (with our assistance) the moisture content of the ginseng roots throughout the drying process to ensure that the drying air temperature was at about 38°C when the moisture content of the ginseng roots was 28 to 30% (w.b.). The grower at site 1, intentionally maintained a drying air temperature of 38°C well before the ginseng roots reached a moisture content of 30% (w.b.).

It is not known if the green colour would have developed if the drying air temperature would have been below 38°C when the ginseng roots were less than 28 to 30% moisture content (w.b.). Both growers did not want to take this chance.

The growers also indicated that the appearance of dried ginseng roots is partially dependent on the degree of washing prior to drying. Both growers washed their roots so that the majority of soil was removed. This highlights the wrinkles on the exterior of the dried ginseng roots which is a desirable characteristic sought by some buyers.

An interesting point brought up by both growers is that there is no method to determine when ginseng roots are dry other than physically breaking the roots and observing its snap. The growers indicated that another method is needed so that they don't overdry the roots.

A perfect example of this is at site 2. Let's assume that the ginseng roots from the last 3 loads, at moisture contents of 5.20 to 7.25% (w.b.), had been dried to a moisture content of 7.66% (w.b.) similar to the first load. The total marketable weight of the last 3 loads would have been 3741 kg instead of 3686 kg. It may seem insignificant, but assuming a market price of $88/kg for dried ginseng roots the additional weight (in the form of water) would increase the gross value of the ginseng roots dried by $4840.

CONCLUSIONS

The following conclusions were drawn from data collected at sites 1 and 2.

1.) Cultivated American ginseng roots can be dried successfully in trays in bulk tobacco kilns.

2.) Ginseng roots were dried in bulk tobacco kilns from initial moisture contents between 68.85 and 71.81% (w.b.) to final moisture contents between 5.20 and 7.66% (w.b.).

3.) The length of time to dry ginseng in bulk tobacco kilns ranged from 14.4 to 17.0 days.

4.) The mass of ginseng roots dried per bulk kiln ranged from 1125 to 1408 kg at moisture contents of 5.20 to 7.66% (w.b.).

5.) Air dry-bulb temperatures and relative humidities during the drying process ranged from 23 to 27°C @ 54 to 80% relative humidity during the initial stage of drying to between 37 and 39°C @ 10 to 30% relative

humidity during the latter stage of drying. Air dry-bulb temperatures were raised slowly during drying while air relative humidities were dropped quickly after 38.0 to 48.0 h of drying.

6.) Total drying energy useage per kg of water removed from the ginseng roots ranged from 11.36 to 15.61 MJ/kg.

7.) Based on 1988 energy costs, electrical and propane costs totalled $0.28 per kg of dried ginseng roots at site 1, while at site 2 electrical and natural gas costs totalled $0.17 to $0.19 per kg of dried ginseng roots.

RECOMMENDATIONS

Monitoring of ginseng drying in bulk tobacco kilns should be continued in 1989 to verify data collected in 1988. In addition, monitoring should include how the appearance and texture of ginseng roots change during drying.

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Li, Y and R. V. Morey. 1987. Thin-layer drying rates and quality of cultivated american ginseng. Transactions of ASAE 30(3): 842-847

Williams, L and J. A. Duke. 1978. Growing ginseng. Farmers Bulletin Number 2201. United States Department of Agriculture, Washington, D.C. 8 pp.

Figure 1G: Ginseng trays in layers in bulk tobacco kiln

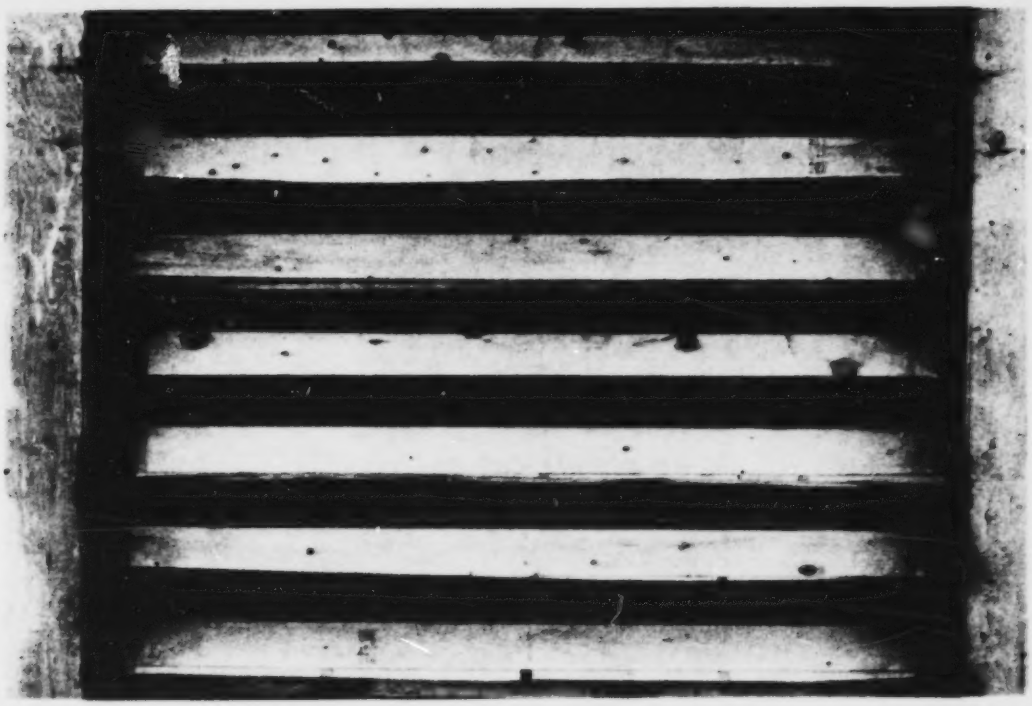

Figure 2G: Ginseng trays in layers in rack

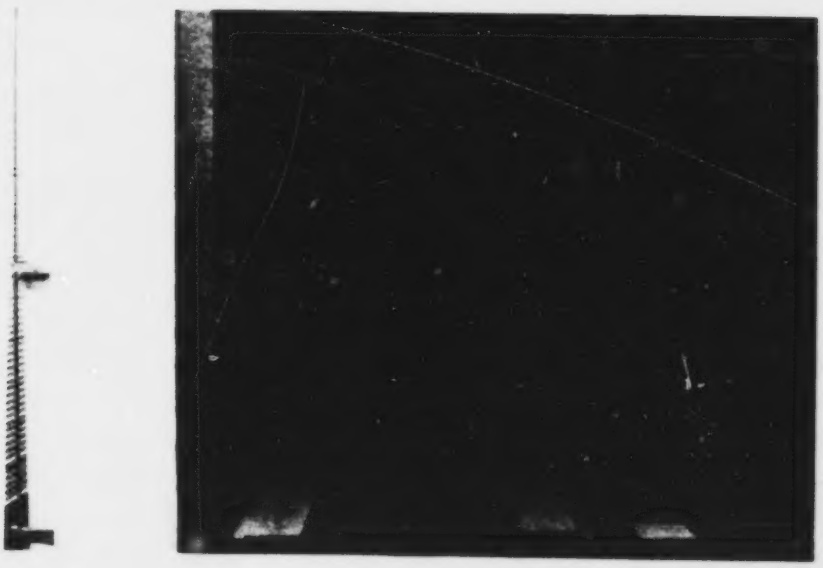

Figure 3G: Ginseng trays stacked at the loading end of a bulk kiln

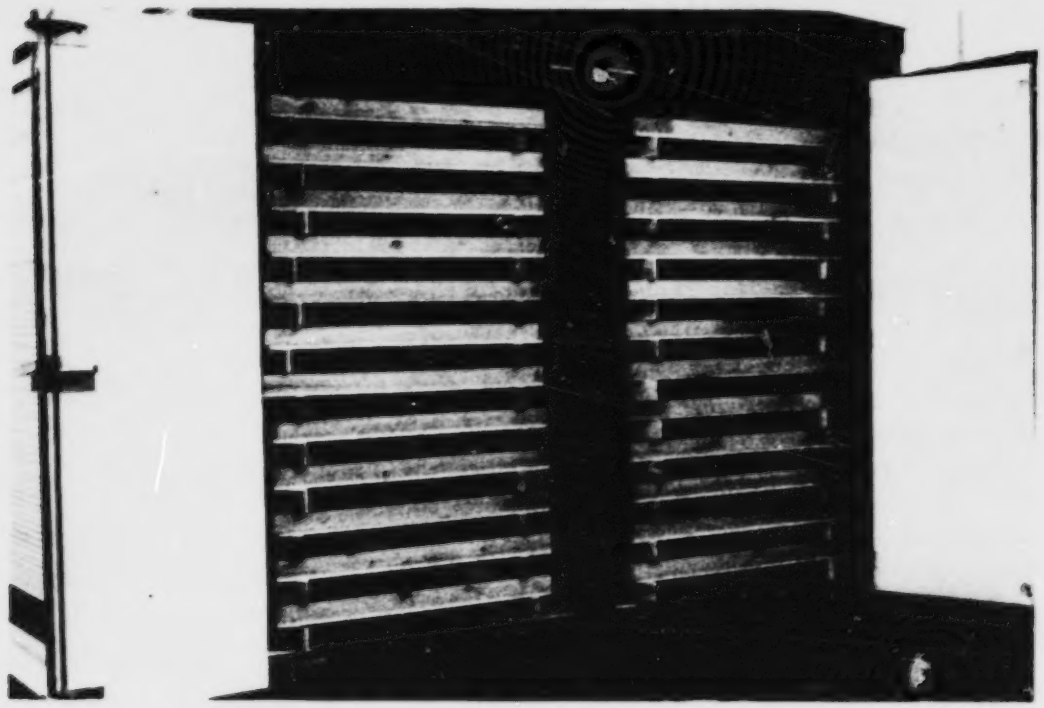

Fig.4G: GINSENG CURING HISTORY -Site 1

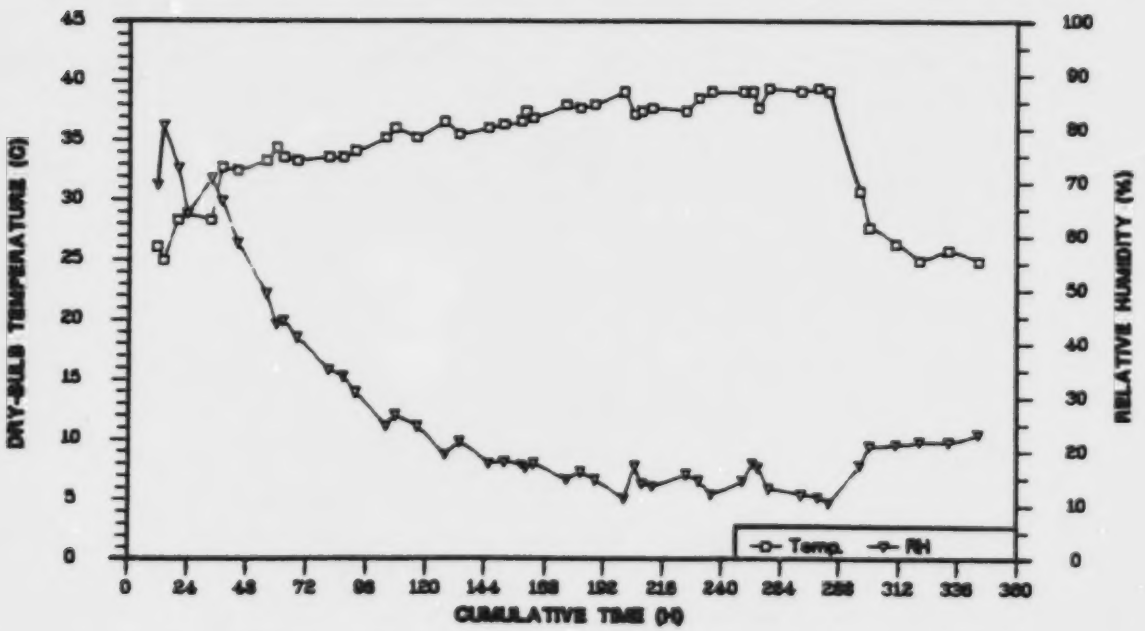

Fig.5G: GINSENG CURING HISTORY -Site 2, Load 1

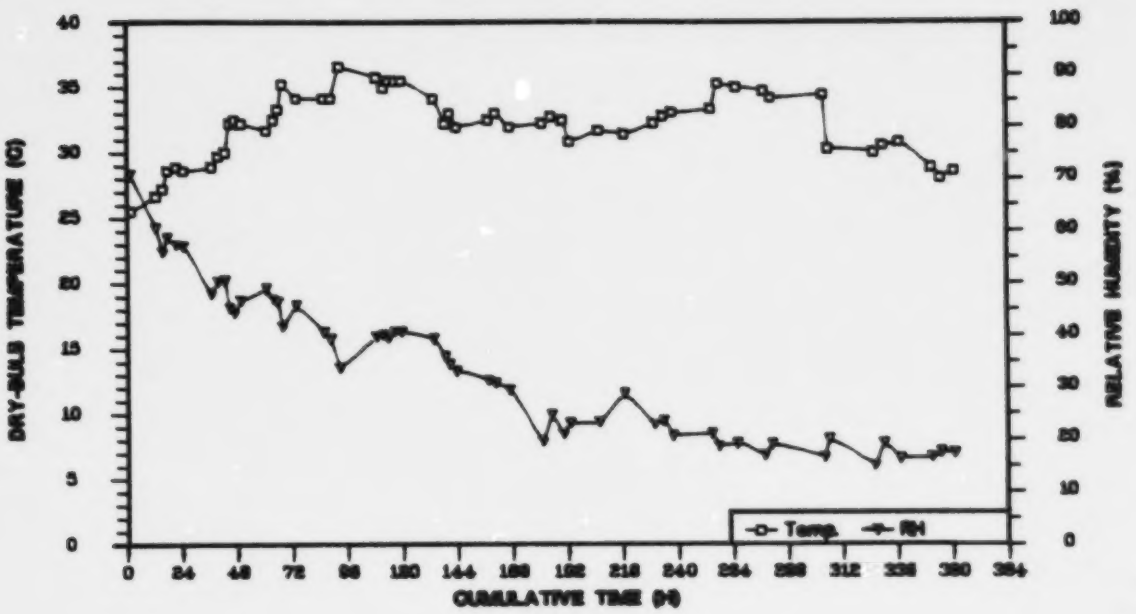

Fig.6G: GINSENG CURING HISTORY -Site 2, Load 2

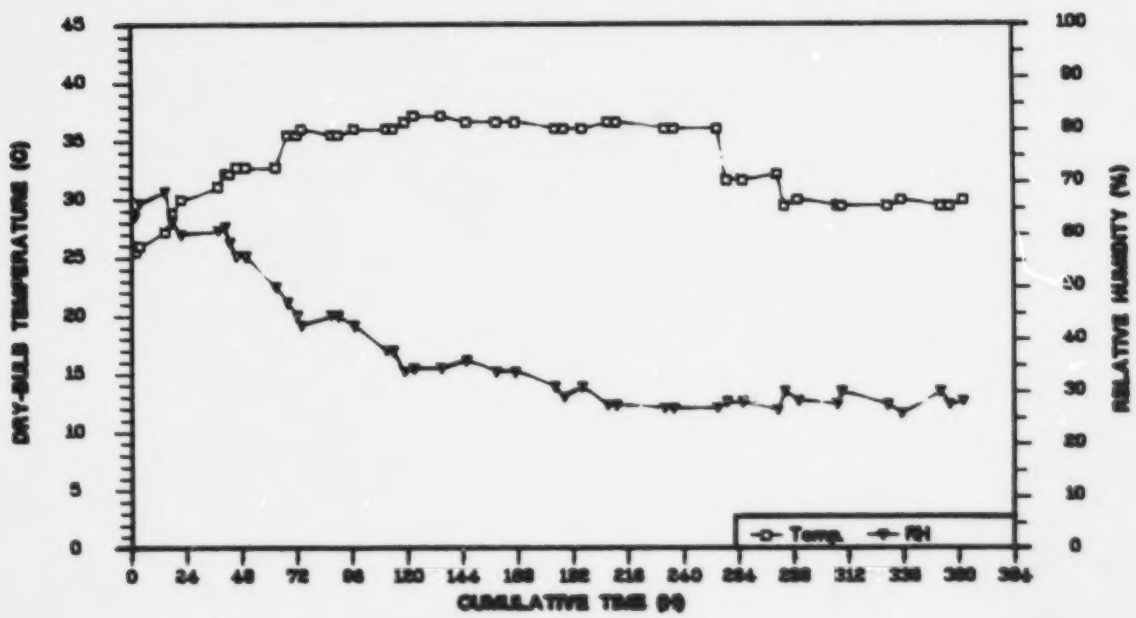

Fig.7G: GINSENG CURING HISTORY -Site 2, Load 3

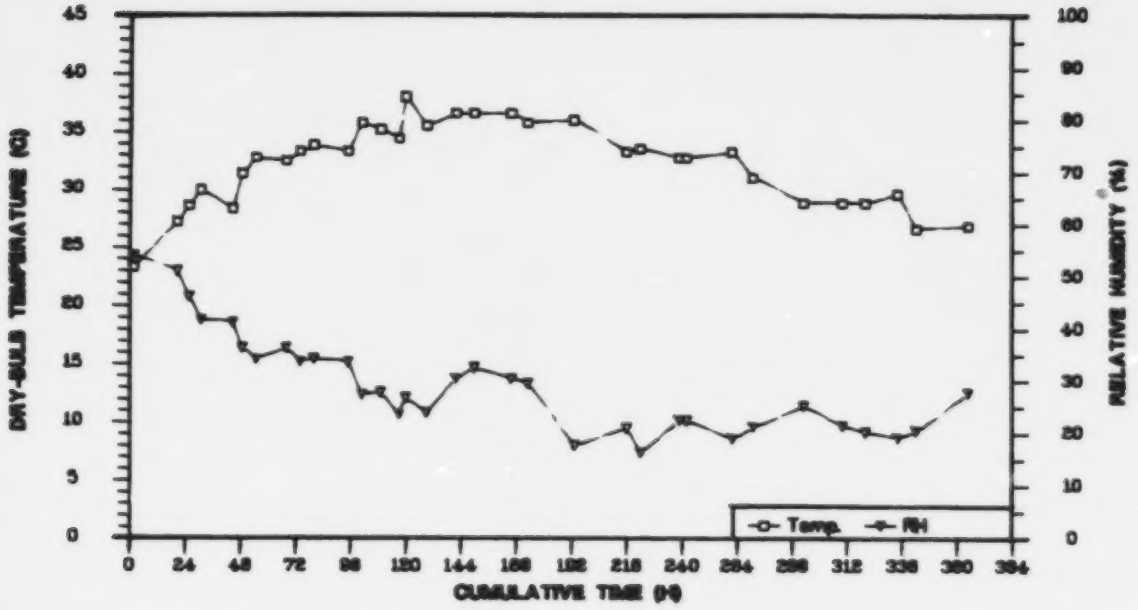

Fig.8G: GINSENG CURING HISTORY -Site 2, Load 4

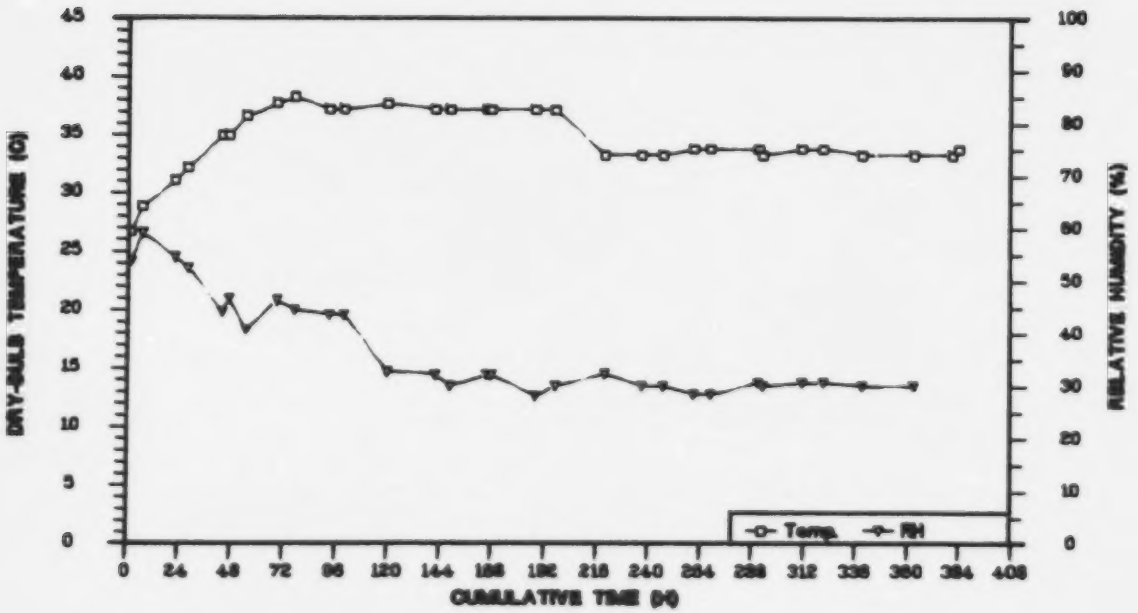

Fig.9G: GINSENG MOISTURE CONTENT DURING DRYING

-Site 1-

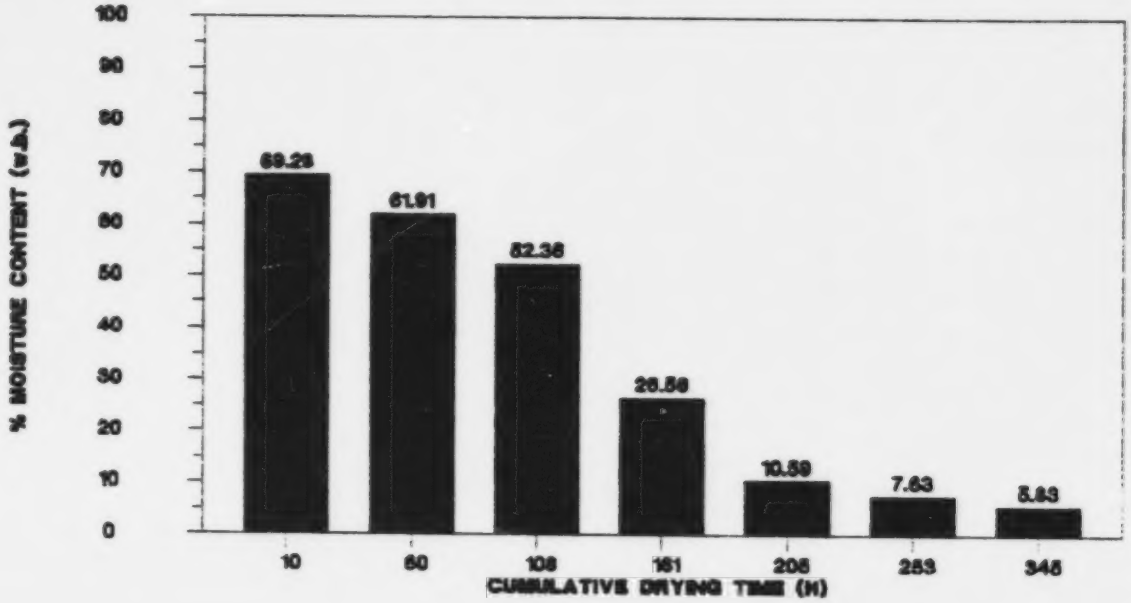

Fig.10G: GINSENG MOISTURE CONTENT DURING DRYING

-Site 2, Load 1-

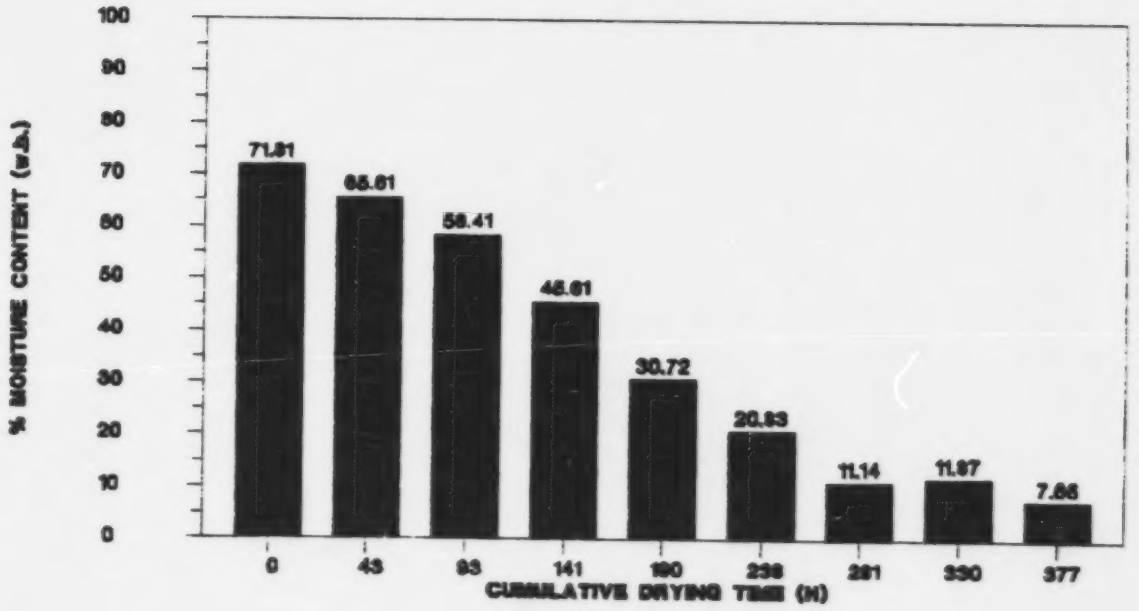

Fig.11G: GINSENG MOISTURE CONTENT DURING DRYING

-Site 2, Load 2-

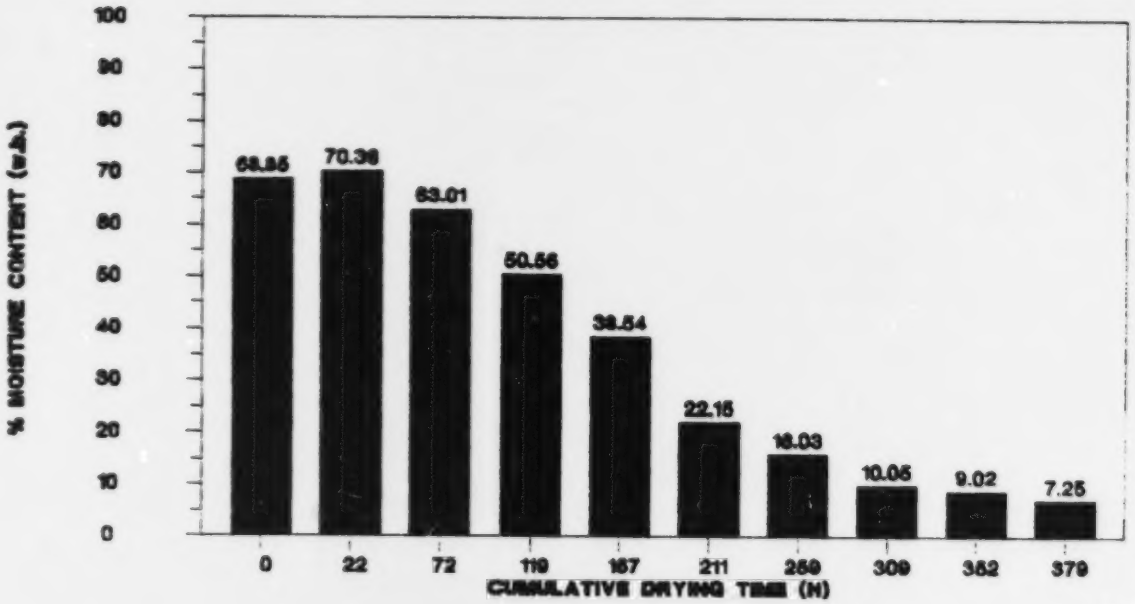

Fig.12G: GINSENG MOISTURE CONTENT DURING DRYING

-Site 2, Load 3-

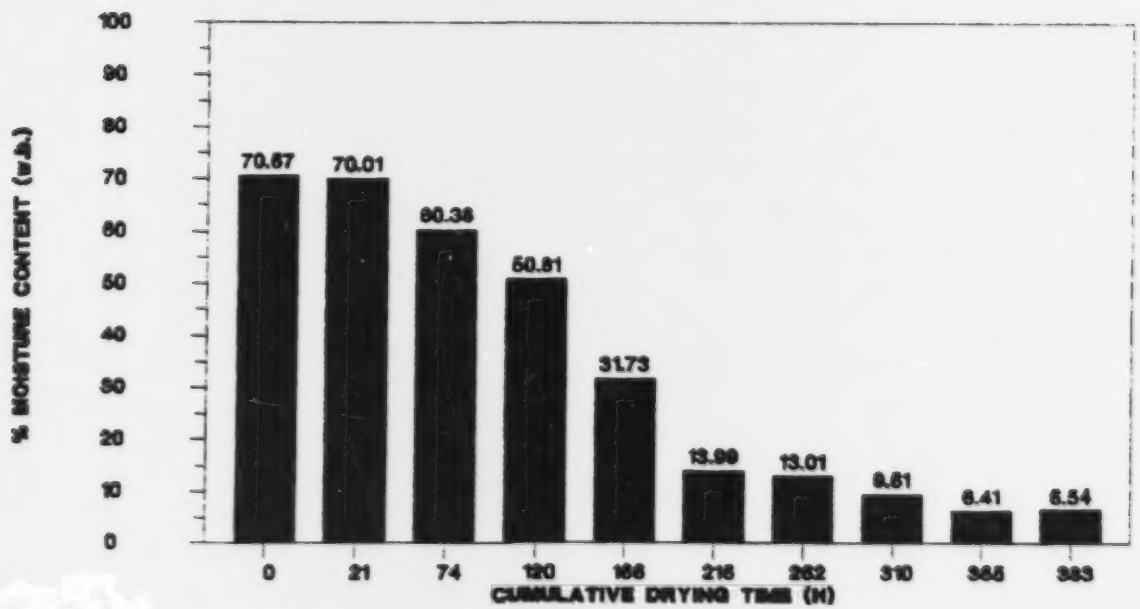

Fig.13G: GINSENG MOISTURE CONTENT DURING DRYING

-Site 2, Load 4-

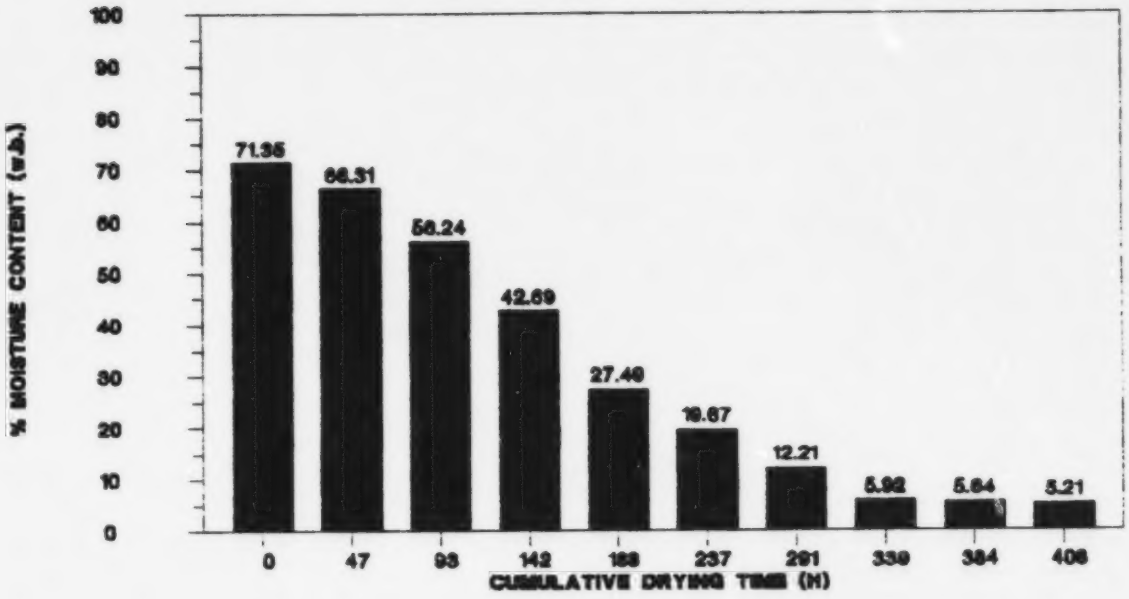

Table 1G: Summary of ginseng drying data

LOAD #	MASS (kg) initial	MASS (kg) dried	MOISTURE CONTENT (%w.b.) initial	MOISTURE CONTENT (%w.b.) dried	DRYING TIME (h)* furnace operation
Site 1					
1	4316	1408	69.28	5.83	345 (14.4 days)
Site 2					
1	4160	1270	71.81	7.66	377 (15.7 days)
2	3585	1204	68.85	7.25	379 (15.8 days)
3	3585	1125	70.67	6.54	383 (16.0 days)
4	4490	1357	71.35	5.20	408 (17.0 days)

*Also includes unloading time

Table 2G: Summary of ginseng drying energy consumption

LOAD #	FUEL propane (L)	FUEL n. gas (m^3)	ELECTRICITY (kWh)	TOTAL ENERGY* (MJ)	WATER REMOVED (kg)	ENERGY USE PER H_2O REMOVED (MJ/kg)
Site 1						
1	1631		1054	45385	2908	15.61
Site 2						
1		734	1435	32838	2890	11.36
2		762	1443	33922	2381	14.25
3		770	1458	34278	2460	13.93
4		875	1553	38578	3133	12.31

*25.5 MJ/L propane, 37.7 MJ/m^3 natural gas and 3.7 MJ/kWh electricity

Table 3G: Summary of ginseng drying costs

LOAD #	FUEL*		ELECTRICITY*	MASS (kg)	TOTAL ENERGY COST PER MASS
	propane ($)	n. gas ($)	($)	dried @ m.c. (w.b.)	($/kg)
Site 1					
1	334.36		59.76	1408 @ 5.83%	0.28
Site 2					
1		128.45	81.36	1270 @ 7.66	0.17
2		133.35	81.82	1204 @ 7.25	0.18
3		134.75	82.67	1125 @ 6.54	0.19
4		153.13	88.06	1357 @ 5.20	0.18

*1988 energy prices: $0.205/L propane, $0.175/m^3 natural gas and $0.0567/kWh for 1-phase electricity

(v) CURING AND STORING SWEET POTATOES IN BULK TOBACCO KILNS

INTRODUCTION

The sweet potato (Ipomoea batatas) is a perennial and a member of the Convolvulaceae or morning-glory family. The sweet potato is grown as an annual in the United States and Canada because of cool air and soil temperatures during the winter months. Sweet potatoes when exposed to air or soil temperatures below 10°C for several hours (referred to as "chilling") will breakdown internally during storage and will be unmarketable.

During the 1940's sweet potatoes were grown in southwestern Ontario for the canning industry. After the '40's interest in sweet potatoes declined because of growth in the tobacco industry. It was not until 1987, when some existing and former tobacco producers were looking for crop alternatives, that interest in growing sweet potatoes was renewed in the tobacco growing areas of the province.

In cooperation with Cindy and Terry Pieters (hereafter referred to as site 1) and John McMahon (hereafter referred to as site 2), the Agricultural Energy Centre initiated a project at both sites in 1988 to determine methods to utilize bulk kilns for curing and storing sweet potatoes.

LITERATURE REVIEW

Curing

Sweet potatoes must be cured if they are to be stored for any length of time. Curing promotes the healing over of cuts, bruises and skinned areas caused by harvesting and handling. This decreases the possibility of decay, such as "soft rot", during storage and also lessens dehydration. Curing also enhances the flavour/sugar content of most sweet potato varieties.

Curing should begin immediately after digging. Optimum curing conditions are: dry-bulb temperature of 30°C; relative humidity of 90 to 95%; continuous air circulation; and sufficient air exchange (Wilson and Abrams, 1982).

Continuous air circulation prevents heat buildup in the upper portion of the curing structure. It also assists in the evaporation of water added

to the curing structure to maintain high humidity levels. Suggested air circulation rates are 30 to 42 L/s per tonne of sweet potatoes (Covington et al, 1976).

Sufficient air exchange is required during curing to replenish O_2 absorbed by the sweet potatoes and to decrease the CO_2 respired by the sweet potatoes. Air exchange also removes any excess heat and moisture accumulation in the curing structure.

The length of time required to cure sweet potatoes usually ranges from 4 to 10 days. Curing is considered complete when cuts and skinned areas of the sweet potatoes have healed. Another indication is when the sweet potatoes produce a few short sprouts (Steinbauer and Kushman, 1971).

Curing usually results in the sweet potatoes loosing up to 5% of their original weight because of water loss from evaporation and dry matter loss from respiratory oxidation of sugars (Steinbauer and Kushman, 1971).

Storage

Optimum storage conditions are an air dry-bulb temperature of 13°C at 85 to 90% relative humidity and sufficient aeration (Wilson and Abrams, 1982). The suggested air circulation rate is similar to that used for curing. Air exchange requirements, needed for the same reasons specified in the curing section, are in the order of 0.4 L/s per tonne of sweet potatoes (ASAE Monograph, 1983). A weight loss of 15% resulting from a 5 month storage period is not uncommon (Steinbauer and Kushman, 1971).

Curing/Storage in Tobacco Kilns

Research conducted in Ontario during the '70's indicates that tobacco kilns can be used for curing and storage of sweet potatoes (Collin, 1981). Collin indicated that installation of a vapour barrier and upgrading of the insulation of a kiln are required. The vapour barrier reduces moisture loss from the kiln so that high humidity levels can be maintained, while the insulation reduces the heating load and allows a consistent curing/storage temperature to be attained. Collin did not indicate if any additional modifications are needed or if the quality of sweet potatoes cured and stored in tobacco kilns is comparable to conventional methods.

Watkins and Wilson (1977) reported that bulk tobacco barns in North Carolina (in Ontario referred to as bulk tobacco kilns) can be modified

to cure and store sweet potatoes, but it is not highly recommended. Before any degree of success can be attained curing and storing sweet potatoes, modifications are necessary to the kiln's structure and furnace unit.

Watkins and Wilson found that tobacco kilns are equipped with furnace units that are over-sized for curing and storing sweet potatoes. Using the existing blower/burner arrangement of the furnace unit, without modifying it, results in sweet potatoes loosing excessive amounts of weight from dehydration and unwarranted energy costs. Other negative aspects of utilizing kilns is their "loose" structure and poor insulation values. A "tight" structure is required to maintain high humidity levels, while proper insulation values will prevent condensation from forming and reduce heat loss.

Watkins and Wilson recommended that if bulk tobacco kilns are utilized for sweet potato curing and storage the following modifications are needed:

1.) reduce heat output of burner to 100 MJ/h;
2.) decrease pully size on motor powering the blower to decrease air flow;
3.) decrease motor size on blower to reduce electrical consumption;
4.) operate blower/burner intermittently during curing/storage;
5.) upgrade insulation values;
6.) install a fan, rated at 700 L/s @ 30 Pa, above the sweet potatoes to provide air exchange and circulation when the blower is not operating.

Van Hooren (1988) indicated that the blower/burner of a bulk tobacco kiln does not have to be utilized to successfully cure and store sweet potatoes. A 4.8 kW heater and a fan rated at 900 L/s @ 90 Pa were used to provide enough heat and aeration during curing/storage. Van Hooren also indicated that the insulation value of the kiln's roof was upgraded to 4.7 RSI to reduce the heating load and prevent condensed moisture from dripping on the sweet potatoes. There was no need to make other modifications to the kiln since it already had a poly vapour barrier and 2.1 RSI insulation in the walls.

PROJECT OBJECTIVES

The sweet potato growers at both sites were supplied with the information cited in the literature review. The growers were then given the opportunity to decide which kiln modifications they would implement. The Agricultural Energy Centre would then evaluate the effects of the kiln modifications in relation to curing and storage of sweet potatoes.

The following would be identified for each site:

1.) kiln modifications;

2.) handling requirements;

3.) air dry-bulb temperature and relative humidity during curing and storage;

4.) energy consumption;

5.) and sweet potato quality after curing and storage.

METHOD

Site 1

Kiln Specifications:

Sweet potatoes were cured and stored in a "Powell", 150 rack, 3 curing compartment, bulk kiln. Inside dimensions of the 2 outside curing compartments are 7270 mm (length) x 1500 mm (width). Inside dimensions of the middle curing compartment are 5590 mm (length) x 1500 mm (width). Height of each curing compartment is 2210 mm (measured from perforated floor to eave of kiln).

The furnace unit of the kiln is equipped with a centrifugal blower powered by a 3.7 kW, single phase motor. The blower is capable of producing an air flow of 5600 L/s @ 370 Pa (kiln manufacturer's rating).

Air circulation in the kiln is as follows: from the lower plenum, through the openings in the steel floor, up through the crop and then it returns to the intake of the furnace. If the ambient air vent on the furnace unit is open some of the air in the kiln will be expelled through exhaust louvres located above the middle curing compartment at the loading end of the kiln.

The burner is direct-fired and fuelled by natural gas. The fuel energy input to the burner is rated at 295 MJ/h.

The roof of the kiln is constructed of 50 mm x 100 mm rafters, 20 mm thick fibreboard (RSI 0.36) and metal roofing. The sidewalls of the

kiln are constructed of 16 mm thick plywood, 75 mm thick fibreglass insulation (RSI 1.55), 50 mm x 100 mm studs and metal roofing. The wall separating the furnace unit from the curing compartments is constructed of 50 mm x 100 mm studs covered with 16 mm plywood on the side facing the curing compartments.

Kiln Modifications:

The growers decided not to make any modifications to their "Powell" bulk kiln. They were growing only 2.5 ha of the "Jewel" variety of sweet potatoes and did not want to invest any money into kiln modifications in the event that the crop was not profitable. In addition, the growers anticipated using the kiln again in 1989 for curing tobacco and were concerned that any modifications to the kiln might affect tobacco curing.

Harvesting and Kiln Loading/Unloading:

The sweet potatoes were dug with a sweet potato harvester from October 5 to 7, 1988. The harvester used consists of a digging elevator and inspection belt. Workers on the harvester sorted the sweet potatoes according to size and condition while placing them into tote boxes. The condition of the majority of sweet potatoes harvested was excellent. The harvester caused very few abrasions on the surface of the sweet potatoes.

The tote boxes containing the sweet potatoes were transported by wagon to the kiln. Each tote box measures 1000 mm x 1130 mm x 70 mm (high) and contained about 450 kg of sweet potatoes.

Various lengths of wooden beams, with dimensions of 75 mm x 75 mm, were placed lengthwise in two rows from the furnace end to the loading end in each curing compartment. The two rows of beams were spaced about 600 mm apart. A tractor mounted fork lift then placed a tote box on the wooden beams at the loading end of the kiln and pushed it towards the burner end. Every tote box loaded thereafter was done in a similar manner until 5 tote boxes were in each of the outer 2 curing compartments and 4 tote boxes were in the middle curing compartment. An additional tote box was then stacked on the tote box nearest the loading end of the kiln in each curing compartment. Thus, a total of 17 tote boxes were loaded into the kiln.

The sweet potatoes from the kiln were graded and marketed as needed from December 16, 1988, to February 11, 1989. During this period, the tote boxes were removed from the kiln and transported to a processing area set-up in the barn. The 2 tote boxes at the loading end of the kiln in each curing compartment were removed using the tractor mounted fork lift. The remaining tote boxes, further in the kiln, were pulled individually to the loading end by a chain attached to the tractor. Each tote box was then removed from the kiln with the tractor mounted fork lift.

Site 2

Kiln Specifications:

Sweet potatoes were cured and stored in a "Bulk Tobac", 4 curing compartment, bulk kiln. Inside dimensions of the 2 outer curing compartments are 10940 mm (length) x 1310 mm (width). Inside dimensions of the inner 2 curing compartments are 9110 mm (length) x 1310 mm (width). Height of each curing compartment is 2090 mm (measured from perforated floor to eave of kiln).

The furnace unit of the kiln is equipped with an axial flow fan powered by a 3.7 kW, single phase motor.

Air circulation in the kiln is as follows: from the upper plenum, through the crop and then returns to the intake of the furnace unit. If the ambient air vents on the furnace unit are open some of the air in the kiln will be expelled through exhaust vents situated along the base of the sidewalls of the kiln.

The burner is direct-fired and fuelled by natural gas. The fuel energy input to the burner can be regulated up to 528 MJ/h.

The roof and walls of the kiln are insulated with 12.7 mm thick polyisocyanurate (foil-faced type). The RSI value of this insulation is 0.72.

Kiln Modifications:

The grower decided to reduce the air flow output of the axial flow fan. The pulley on the 3.7 kW motor operating the fan was changed to a smaller size. After curing, the 3.7 kW motor was replaced with a 0.7 kW motor to reduce electrical requirements for storage. No other modifications were undertaken to the structure or operation of the kiln.

Harvesting and Kiln Loading/Unloading:

"Jewel" and "Georgia Jet" varieties of sweet potatoes were dug with a modified potato digger from October 3 to 5, 1988. The sweet potatoes were partially graded for culls and loaded into 450 kg tote boxes. It was observed that the sweet potatoes were cut and bruised considerably more than those at site 1.

A total of 50 tote boxes of sweet potatoes were loaded in the 4 curing compartments of the kiln. Since the kiln has a concrete floor, a fork lift truck was used for loading. The tote boxes were stacked two high in each curing compartment.

The sweet potatoes were graded and marketed as needed from November 21 to December 16, 1988. During this period, the tote boxes were removed from the kiln using the fork lift truck and transported to a temporary processing area in the barn.

Curing/Storage Air Conditions

Growers at both sites attempted to use the following curing/storage air conditions in their kilns.

Curing: - 30°C dry-bulb temperature
- 90% relative humidity
- continuous air circulation
- minimal air exchange (opening and closing the loading doors daily)

Storage: - 13°C dry-bulb temperature
- 85 to 90% relative humidity
- intermittent air circulation at site 1 and continuous air circulation at site 2
- minimal air exchange (opening and closing the loading doors daily).

MONITORING

Site 1

Air flow produced by the blower of the kiln was measured prior to curing with an "Alnor" velometer. During curing and storage air dry-bulb temperature and relative humidity were recorded using two thermohygrographs.

One thermohygrograph was positioned on the perforated floor at the furnace end of one of the outer curing compartments, while the other thermohygrograph was positioned in the middle curing compartment at the loading end above the sweet potatoes.

Electrical consumption of the blower motor was recorded during curing and storage from the kWh meter servicing the farm. Natural gas consumption of the burner was recorded during curing and storage using a natural gas meter that was installed on the kiln.

Sample lots of sweet potatoes were bagged and weighed before curing and placed in the tote boxes. During storage the sample lots were weighed again. This was done to determine the % weight loss resulting from curing and storage. A few of the sweet potatoes were analyzed for starch content before curing and again during storage. This was done to determine if any starch to sugar conversion had occurred during curing. The growers also maintained records pertaining to the effects of curing and storage on the sweet potatoes.

Site 2

Air flow produced by the fan of the kiln was measured prior to curing with a "Alnor" velometer. During curing and storage air dry-and wet-bulb temperatures at various locations in the kiln were recorded at 1.0 h intervals using "K" type thermocouples connected to a "Kaye Digistrip III" datalogger.

A volt-amp meter was used to determine the electrical consumption of the fan motors used for curing and storage. Natural gas consumption of the burner during curing and storage was recorded with a natural gas meter installed on the kiln.

Sample lots of sweet potatoes were bagged and weighed prior to curing and placed in the tote boxes. During storage the sample lots were weighed again. This was done to determine the % weight loss resulting from curing and storage. A few of the sweet potatoes were analyzed for starch content before curing and again during storage. This was done to determine if any starch to sugar conversion had occurred during curing.

The grower also maintained records pertaining to the effects of curing and storage on the sweet potatoes.

RESULTS AND EVALUATION

Curing and Storage Air Conditions

Site 1:

Air flow produced by the blower of the kiln was measured prior to curing and determined to be 4040 L/s. During curing and storage, air flow through the sweet potatoes was not measured since it could not have been done accurately. It was observed however that the majority of air circulating in the kiln was travelling around the tote boxes of sweet potatoes since about 50% of the perforated floor of the lower plenum was not covered by the tote boxes. This was probably to the growers' advantage. If all of the air circulating in the kiln had gone through the sweet potatoes, the air flow rate could have been as high as 528 L/s/tonne of sweet potatoes which is considerably greater than the recommended air flow rate of 30 to 42 L/s/tonne. At that high an air flow rate a considerable amount of dehydration to the sweet potatoes would have occurred.

Curing began October 7, 1988, at 3:30 p.m. and concluded October 11, 1988, at 9:00 a.m. Thus, the curing period was 89.5 h or 3.7 days. Most of the cuts on the sweet potatoes had healed during the curing period. However, this was not the reason for lowering the air dry-bulb temperature to storage conditions. Sprouts on the sweet potatoes started to develop on the second day of curing and had reached a length of 20 to 30 mm by the fourth day of curing. It was feared that if the sprouts continued to get longer the sweet potatoes would eventually become unmarketable. Lowering the air dry-bulb temperature to storage conditions stopped the sprout development.

Storage conditions were maintained until February 11, 1989, at 9:30 a.m. Total storage time was 2952.5 h or 123.0 days. It should be noted that during the storage period sweet potatoes were removed from the kiln as needed (and marketed) from December 16, 1988 to February 11, 1989.

Figure 1Sp, indicates the daily average air dry-bulb temperature and relative humidity recorded in the kiln during curing (up to 3.7 days) and storage (3.7 to 123.7 days). During curing the air dry-bulb temperature ranged between 32 and 37°C, while the air relative humidity ranged between 88 and 91%. During storage the air dry-bulb temperature ranged between 26 and 8°C, while the air relative humidity ranged between 93 and 45%.

The curing air dry-bulb temperatures used were all higher than the

recommended curing air dry-bulb temperature of 30°C. An inaccurate thermostat was responsible for air temperatures being higher than that recommended. It should also be noted that the 265 MJ/h burner caused a large increase in air temperature during its on cycle. This is not evident in figure 1Sp because it only indicates the daily average air dry-bulb temperature.

The fluctuations in air dry-bulb temperature during storage can be attributed mostly to the response of the burner thermostat to changes in the ambient air temperature. Even though the thermostat temperature setting remained unchanged during most of storage, large changes in the ambient air temperature affected the thermostat and caused it to either decrease or increase the air dry-bulb temperature in the kiln.

Air relative humidity was maintained at a high level during curing by continuously adding water (from a garden hose) on to the concrete pad in the lower plenum of the kiln. Maintaining a high level of humidity in the kiln during storage was difficult and it dropped below the recommended storage air relative humidity of 85 to 90% on a number of occasions. The humidity could not be maintained because water could not be added to the kiln (through the hose) when the ambient air temperature was at freezing or below. In addition, humidity within the kiln could not be held in for long periods when no water was added because the kiln does not have a vapour barrier.

Site 2:

Air flow produced by the fan of the kiln was measured prior to curing and determined to be 1470 L/s. Similar to site 1, air flow was not measured through the sweet potatoes during curing and storage but again it was observed that the majority of air was travelling around the tote boxes of sweet potatoes.

Curing began October 4, 1988, at 10:30 p.m. and concluded October 11, 1988, at 11:00 a.m. Thus, the curing period was 156.5 h or 6.5 days. Completion of curing was indicated by the healing of most of the cuts on the sweet potatoes. No sprouts developed on the sweet potatoes during curing which is opposite to what occurred at site 1.

Storage conditions were initiated immediately after completion of curing and maintained until December 16, 1988, at 10:00 a.m. Total storage

time was 1583.0 h or 66.0 days. It should be noted that during the storage period sweet potatoes were removed from the kiln as needed (and marketed) from November 21 to December 16, 1988.

Figure 2Sp indicates the average daily air dry-bulb temperature and relative humdity recorded in the kiln during curing (up to 6.5 days) and storage (6.5 days to 66.0 days). The air dry-bulb temperature was increased from 16°C during the first day of curing to between 25 and 28°C for the remainder of curing, while the air relative humidity ranged between 80 and 90%. During storage the air dry-bulb temperature ranged mostly between 11 and 15°C, while the air relative humdity was usually between 75 and 90%.

The air dry-bulb temperature and relative humidity during curing and storage was more consistent at this site than at site 1 and closer to recommended curing and storage air conditions. This can be attributed to a number of factors: the kiln's structure at site 2 is "tighter" than the kiln at site 1; lower air flows were used at site 2; the burner thermostat at site 2 was not affected by ambient air temperature fluctuations; and the fuel input to the burner at site 2 was decreased to prevent large temperature increases when the burner cycled on.

It should also be noted that water was added (through a garden hose) on to the concrete floor of the kiln to maintain high humidity levels. Again similar to site 1, no water was added when the ambient air temperature was at or below freezing. But since the kiln at site 2 is "tighter" than at the kiln at site 1, humidity was maintained in the kiln for longer periods which resulted in less fluctuation in humidity levels.

Sweet Potato Quality

Table 1Sp indicates the starch content of sweet potatoes sampled prior to curing and during storage at both sites. It would appear that the curing process at both sites resulted in starch to sugar conversion. In addition, it appears that at site 1 a greater amount of starch to sugar conversion occurred than at site 2.

Table 2Sp indicates the percentage weight loss of the sweet potatoes resulting from curing and storage at both sites. At site 1, the sweet potatoes were evaluated for weight loss on the 66th day of storage (December 16, 1988). The percentage weight loss of the Jewel variety of sweet potatoes

was about 10%. At site 2, the sweet potatoes were evaluated for weight loss from the 48th to 66th days of storage. The percentage weight loss was about 23% for both the Jewel and Georgia Jet varieties of sweet potatoes.

Even though curing and storage air conditions at site 1 were not maintained as close to that recommended, the percentage weight loss was about half of that recorded for site 2. This can probably be attributed to the condition of the sweet potatoes prior to curing. The sweet potatoes at site 1 had very few cuts from harvesting whereas the sweet potatoes at site 2 had considerably more. It is thought that with more cuts on sweet potatoes a higher level of dehydration occurs which could be responsible for the higher percentage of weight loss at site 2.

The growers at both sites were satisfied with the quality of their sweet potatoes resulting from curing and storing them in their kilns. They indicated that the majority of sweet potatoes cured and stored were marketed successfully. The grower at site 2, however, did indicate that the potato digger used requires further modifications to reduce the amount of cuts it causes on the sweet potatoes.

Energy Consumption

Table 3Sp indicates the amount of energy consumed for curing and storage of sweet potatoes at both sites. The total cost (based on 1988 energy prices) was $533.48 for 3.7 days of curing and 123.0 days of storage at site 1 whereas at site 2 it was $215.63 for 6.5 days of curing and 66.0 days of storage.

CONCLUSIONS AND RECOMMENDATIONS

The effects of curing and storage of sweet potatoes in bulk tobacco kilns can not be summarized from only one year's data. The project should be continued in 1989 to verify the results from this year's project.

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Fig.18p: SWEET POTATO CURING/STORAGE HISTORY

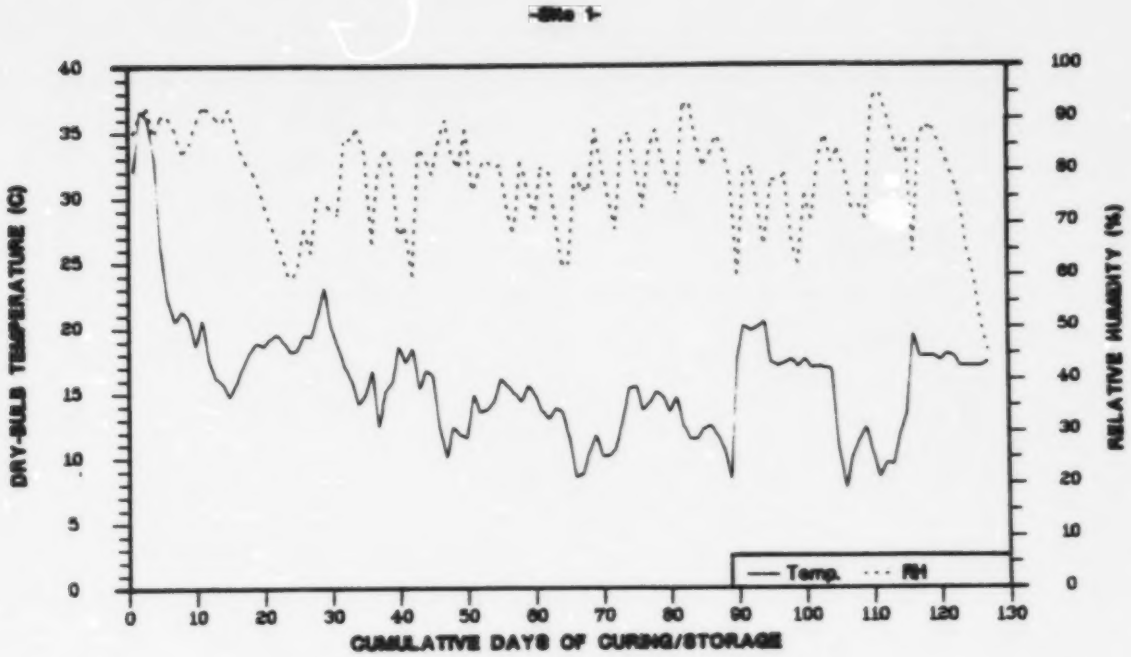


Fig.28p: SWEET POTATO CURING/STORAGE HISTORY

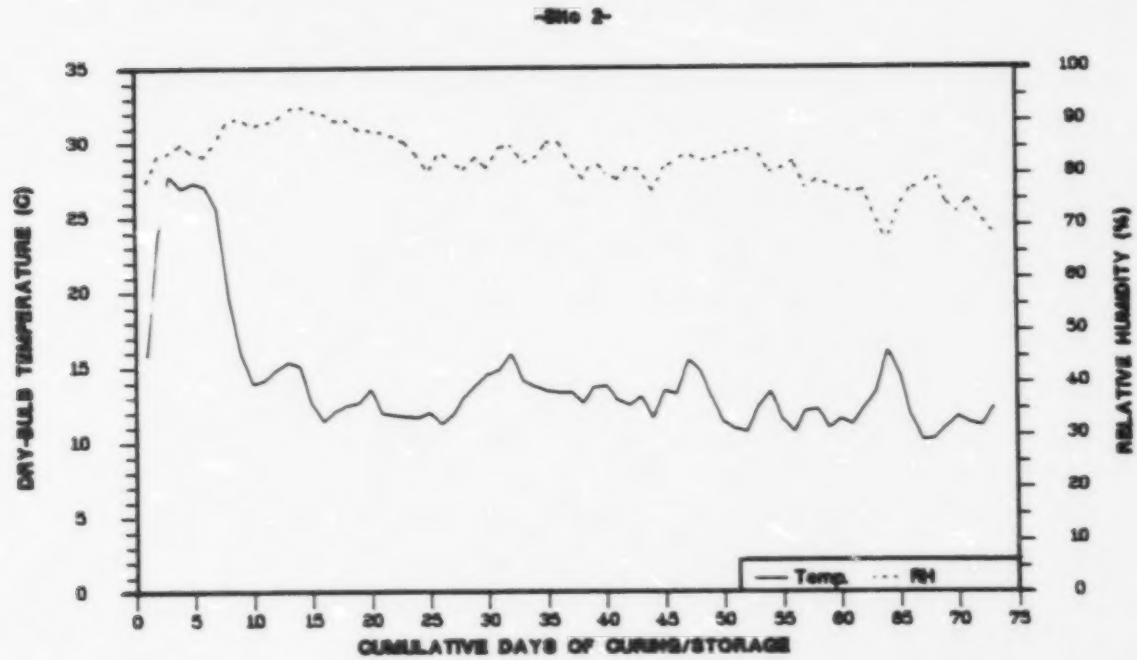


Table 1Sp: Sweet potato starch analyses

SITE #	SWEET POTATO VARIETY	DATE SAMPLED (1988)	% DRY WEIGHT	STARCH % of fresh weight	STARCH % of dry weight
1	Jewel	Oct. 5,6*	18.30	9.0	49.2
	Jewel	Dec. 16**	17.81	3.4	19.1
2	Jewel	Oct. 3*	22.19	11.9	53.6
	Jewel	Nov.28, Dec.2,16**	22.03	7.4	33.6
2	Georgia Jet	Oct. 4, 5*	19.09	9.4	49.2
	Georgia Jet	Nov.28, Dec.16**	20.94	7.8	37.2

* prior curing
** after curing and during storage
NOTE: Analyses provided by Dr. N. Rosa, Plant Pathologist, Agriculture Canada, Research Station, Delhi.

Table 2Sp: Percentage weight loss of sweet potatoes after curing and during storage

SITE #	SWEET POTATO VARIETY	HARVEST WEIGHT (kg)	POST-CURING WEIGHT (kg)	(date)	WEIGHT LOSS (%)
1	Jewel	108.8	98.5	(Dec. 16)	9.47
2	Jewel	124.8	96.4	(Nov. 28 - Dec. 16)	22.76
	Georgia Jet	215.4	165.9	(Nov. 28 - Dec. 16)	22.98

Table 3Sp: Sweet potato curing and storage energy requirements

SITE #	STAGE	PERIOD OF TIME IN HOURS (days)	ENERGY CONSUMPTION		TOTAL ENERGY COST* ($)
			natural gas (m^3)	electricity (kWh)	
1	curing	89.5 (3.7)	142	256	39.37
	storage	2952.5 (123.0)	770	6338	494.11
				TOTAL =	533.48
2	curing	156.5 (6.5)	127	828	69.17
	storage	1583.0 (66.0)	360	1472	146.46
				TOTAL =	215.63

*$0.175/$m^3$ natural gas, $0.0567/kWh electricity

(vi) FLOWER DRYING IN DOWNDRAFT TOBACCO KILNS

BACKGROUND

In 1987, the Agricultural Energy Centre was approached by Cornelis Keeren, Oakville, to investigate artifical drying of flowers in tobacco kilns. The objective was to preserve the original colour of flowers when dried. A pilot project was conducted at the Agriculture Canada Research Station, Delhi, that involved drying celosia and roses using different combinations of heat and fan-forced air. Results of the project indicated that these flowers will retain most of their original colour when dried using fan-forced air with or without heat.

In 1988, Mr. Keeren contracted several farmers to each grow 0.10 to 0.20 ha of various types of flowers for the fresh and dried flower markets. In cooperation with Mr. Keeren, an on-farm project was conducted to determine the effects of drying flowers intended for the dried flower market using fan-forced, ambient air in a downdraft kiln. Statice, Lonas, Strawflowers and Larkspur, all different varieties of flowers, were dried in the kiln.

This report describes the on-farm project:

1.) method used to load the flowers into the kiln;
2.) conditioning procedure used to dry the flowers;
3.) moisture contents of the flowers before and after drying;
4.) appearance of the dried flowers;
5.) and energy requirements and cost to dry the flowers in the kiln.

METHOD

Flower Preparation and Kiln Loading

The contracted growers hand harvested their flowers (with stems) according to the maturity of the flowers from July 20 to August 27, 1988. Preparation of the flowers for drying involved tying the stems of the flowers together in bunches of ten and placing the bunches stem up over laths. Usually ten bunches were spaced uniformily across each lath. The laths of flowers were then hung temporarily inside of a building on the growers' farms ready to be transported to the downdraft kiln. The period of time between harvesting and loading the laths of flowers into the kiln was usually 1 to 3 days.

The laths of flowers were hung by hand in the downdraft kiln, similar to the method used for hanging laths of tobacco on the tiers in a kiln. (as shown in figure 1F). Laths of flowers were grouped together in different

locations in the kiln according to flower variety and colour. The flowers were loaded into the downdraft kiln on eight dates: July 20, 27, 29, 31, August 6, 13, 20, and 27. About 53% of the downdraft kiln's 1200 lath capacity was utilized to dry the flowers.

Kiln Specifications

The exterior dimensions of the low profile, downdraft kiln used are 10000 mm (length) x 6100 mm (width) x 3500 mm (height from grade to eave). The kiln's roof and wall are not insulated.

The kiln is equipped with a "T.C.S." furnace unit. The fuel energy input of the burner is 790 MJ/h, however, since only unheated ambient air was utilized for drying the burner was not used. The axial flow fan of the furnace operates at 430 r.p.m. and is capable of circulating air within the kiln at 4720 L/s (manufacturer's rating). The fan is belt driven by a 0.7 kW electric motor. The total amount of ambient air that can be introduced in the kiln is 1190 L/s when the fresh air intake vents on the furnace unit are completely open.

Drying Procedure

No structural or operational modifications were undertaken to dry the flowers with ambient air in the downdraft kiln. Drying began on July 20 and continued until September 10. During this period the fan of the furnace unit operated continuously and the fresh air intake vents were completely open. The introduction of ambient air into the kiln created a positive pressure within the kiln and forced air containing moisture (released from the flowers) out through an exhaust vent on the furnace unit.

MONITORING

After the laths of flowers had been loaded into the kiln, the number of laths, bunches per lath and flowers per bunch were counted and recorded. The variety and colour of these flowers were also recorded and coded. Three to 5 laths of flowers were selected from each coded group and weighed. This was done to establish an initial weight of the flowers. Weighing of the laths occurred again at the completion of drying. The initial and final weights were used to determine the amount of water removed from the flowers during drying.

Samples were also taken from each coded group of flowers prior to and after drying to determine initial and final moisture contents, respectively. An oven-dry method of 103°C for 24 hours was used to determine moisture content.

Throughout the drying period, a thermohygrograph was used to record air dry-bulb temperature and relative humidity conditions inside the kiln.

RESULTS AND EVALUATION

Drying Data

The results of drying different varieties of flowers in the downdraft kiln are shown in table 1F.

The initial moisture contents of the flowers when loaded into the kiln were between 20 and 86% (w.b.). There was a large difference between some of the initial moisture contents of the flowers because some drying had occurred after the flowers were harvested and before they were loaded in the kiln.

The majority of flowers, once loaded into the kiln, were subjected to fan-forced, ambient air conditions until September 10, 1988. The only exception was the Larkspur variety loaded July 31 and August 6. It was removed from the kiln on August 19. Air conditions within the kiln from the first day the flowers were loaded into the kiln (July 20) to when they were removed ranged from 3 to 36°C while the relative humidity ranged from 35 to 90%.

The final moisture contents of the flowers after completion of drying was relatively consistent and ranged between 9 and 16% (w.b.). Drying removed an estimated 263 kg of water from the 493 kg of fresh flowers loaded into the kiln.

Physical Appearance and Characteristics of Flowers

The appearance of the dried flowers was considered excellent. There was no noticeable discolouration or bleaching of the flower petals. Initial size of the flowers was also not noticeably changed by drying the flowers. Stems of the flowers were straight and firm from hanging inverted.

The delicate nature of some of the flowers dried did create an undesirable characteristic. The Larkspur variety had to be handled very carefully so it would not loose its petals. Strawflowers were found to

be least delicate and could be handled roughly without loosing any petals.

Energy Consumption

Electrical consumption to dry the flowers totalled 1216 kWh. The drying cost totalled $68.95 (based on an electrical cost of $0.0567/kWh). It is suspected that the drying cost would have been less if all of the flowers could have been loaded and dried together.

CONCLUSIONS

1.) Flowers can be successfully dried with fan-forced, ambient air in downdraft kilns.
2.) Flowers dried in the downdraft kiln reached an equilibrium moisture content with ambient air conditions in less than 50 days.
3.) Dried flowers maintain a desirable appearance when subjected to fan-forced ambient air drying.
4.) Loading flowers by hand appears to be efficient, although care is required when unloading dry flowers to prevent their petals from falling off.
5.) Drying energy consumption might have been reduced if the flowers had been loaded and dried together.

RECOMMENDATIONS

The project should be continued in 1989 to examine the time it takes to dry flowers with fan-forced ambient air, in a downdraft kiln when the flowers are loaded on one date. In addition, drying flowers using heated air should be investigated to determine the effects on length of cure and energy costs.

An examination of other flower varieties that could be dried in tobacco kilns would also be beneficial to the dried flower industry.

Figure 1F: Laths of flowers hanging on tiers in downdraft kiln

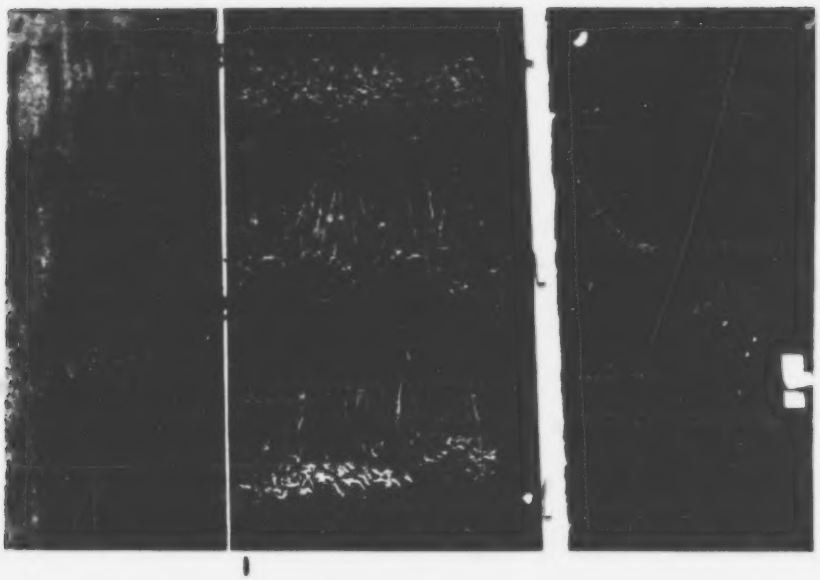


TABLE 1F: Flower drying data

LOADING DATE CODE	FLOWER VARIETY AND COLOUR	NET FRESH WT.(kg)	INITIAL M.C. %(w.b.)	FINAL M.C. %(w.b.)	H_2O REMOVED (kg)	LENGTH OF DRYING* h (days)
July 20						
1A	Statice, Mixed	20.23	66.7	13.2	12.47	1195.5/(49.8)
3A	Lonas, Flesh Tone	2.60	64.4	15.1	1.51	" "
4A	Statice, Yellow	9.00	56.6	14.0	4.46	" "
5A	Statice, White	7.98	66.6	15.3	4.83	" "
6A	Statice, Pink/purple	4.80	63.8	14.2	2.77	" "
July 27						
1B	Statice, Mixed	30.40	74.0	13.2	21.29	1053.1/(43.9)
2B	Strawflower, Mixed	59.25	59.9	14.2	31.56	" "
4B	Statice, Yellow	4.30	63.3	13.7	2.47	" "
5B	Statice, White	10.03	64.4	13.6	5.90	" "
July 29						
2C	Strawflower, Mixed	31.63	86.4	15.1	26.56	1028.2/(42.8)
July 31						
1D	Statice, Mixed	21.47	20.0	12.7	1.80	957.2/(39.9)
2D	Strawflower, Mixed	66.00	78.9	15.5	49.52	" "
4D	Statice, Yellow	1.80	58.0	14.0	0.92	" "
8D	Larkspur, Mixed	9.75	49.3	9.2	4.31	434.0/(18.1)
Aug. 6						
1E	Statice, Mixed	66.50	49.2	13.5	27.45	789.2/(32.9)
4E	Statice, Yellow	3.27	51.6	12.9	1.45	" "
5E	Statice, White	3.00	59.4	14.9	1.57	" "
6E	Statice, Pink/purple	2.33	56.7	14.7	1.15	" "
8E	Larkspur, Mixed	1.70	27.4	5.7	0.39	266.0/(11.1)
Aug. 13						
1F	Statice, Mixed	28.80	40.7	13.6	9.03	642.8/(26.8)
2F	Strawflower, Mixed	45.50	80.1	15.7	34.76	" "
4F	Statice, Yellow	3.83	68.5	12.6	2.45	" "
6F	Statice, Pink/purple	1.40	54.6	13.8	0.66	" "
Aug. 20						
1G	Statice, Purple	27.50	24.8	13.6	3.56	477.3/(19.9)
4G	Statice, Yellow	10.08	57.8	13.6	5.16	" "
Aug. 27						
1H	Statice, Mixed	19.73	35.0	14.1	4.80	308.4/(12.9)

TOTAL NET WEIGHT IN = 492.88 kg
TOTAL NET WEIGHT OUT = 230.08 kg

TOTAL WATER REMOVED = 262.80 kg

*NOTE: UNLOADING DATES: LARKSPUR on Aug. 19 and the rest of the flower varieties on Sept. 10, 1988.

APPENDIX A: Description of tobacco kilns and pack barns

DOWNDRAFT KILNS

Two distinct styles of downdraft kilns exist: high profile and low profile. High profile downdraft kilns have exterior dimensions of about 7300 mm (l) x 6800 mm (w) x 4500 mm (h) whereas low profile downdraft kilns have exterior dimensions of about 10000 mm (l) x 6100 mm (w) x 3500 mm (h). The height measurement of both kiln styles is from grade to the eave.

Downdraft stick kilns are fan-forced, tobacco curing systems. Air is forced through the tobacco by an axial flow fan contained in an external, wall mounted, metal clad duct (commonly referred to as a blower/burner duct). The fan operates at approximately 430 r.p.m. and delivers 3700 to 4700 L/s of air. The fan is belt driven by a 0.7 kW electric motor.

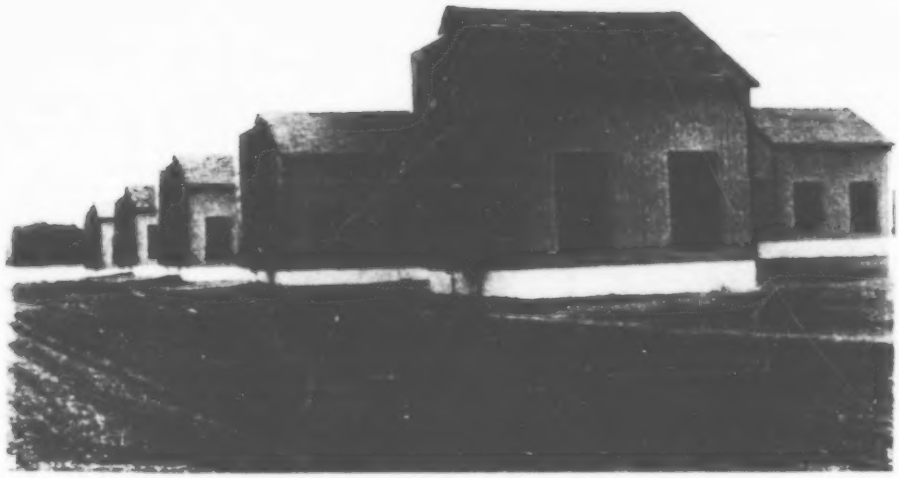
Air within a downdraft kiln passes up through the blower/burner duct into the upper plenum of the kiln, downward through the hanging tobacco and returns either to the air intake of the blower/burner duct or is expelled out exhaust louvres.

Air exchange is controlled by adjustment of the fresh air intake vent(s) located on the blower/burner duct. Opening the air intake vent(s) allows cooler, drier air to be drawn into the kiln. This pressurizes the kiln. On the majority of kilns two pressure sensitive exhaust louvres, located to the sides of the blower/burner on the lower corners of the kiln wall, relieve the internal pressure by allowing moisture-laden air to escape to the atmosphere.

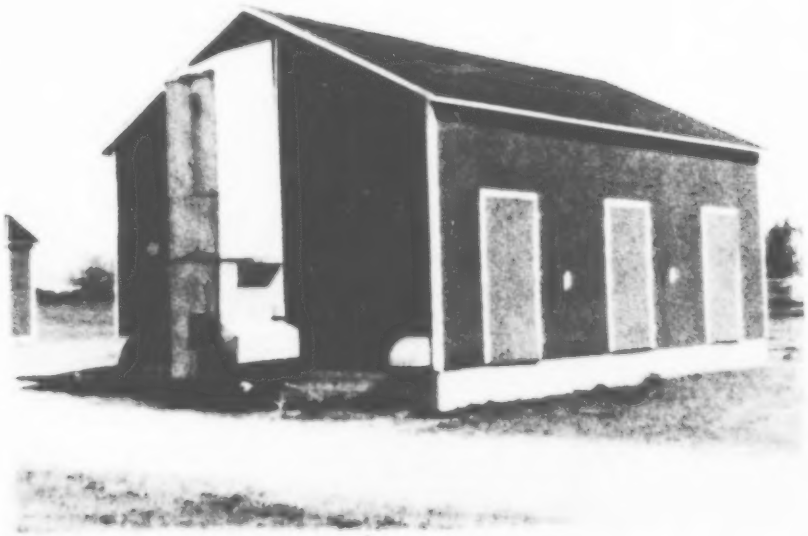
Downdraft kilns are direct-fired with natural gas, propane or no. 2 oil. The fuel energy input of the burners will vary with many being in the range of 740 to 790 MJ/h.

The majority of downdraft kilns were constructed without insulation thirty to forty years ago. Due to increasing energy costs many downdraft kilns have since been partially or completely sealed with polyurethane foam.

High profile downdraft kilns



Low profile downdraft kilns



BULK KILNS

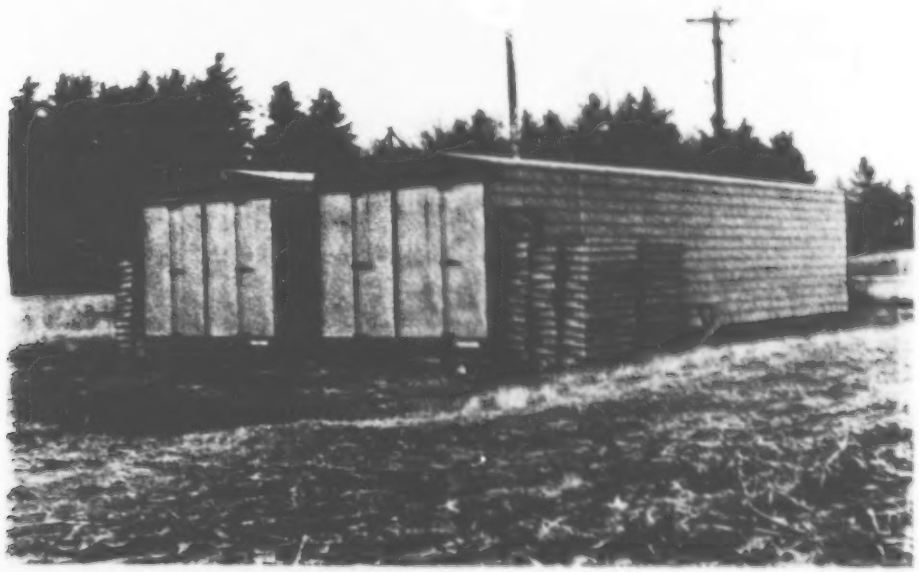
The construction of bulk kilns differs appreciably from downdraft kilns. Typical exterior dimensions of a bulk kiln are about 12500 mm (l) x 3050 mm (w) x 3330 mm (h). Depending upon the manufacturer, many kilns are insulated with fibreglass batts in the walls and expanded polystyrene on the under-side of the roof.

The direction of air circulation in bulk kilns is the reverse of that in downdraft kilns. Air is forced into the lower plenum of the kiln and up through a perforated metal floor. The air then passes through the tobacco and either recirculates to the blower/burner unit or is expelled out exhaust louvres located above the loading doors of the kiln. Similar to the method of air exchange in downdraft kilns opening the fresh air intake vent(s) on the blower/burner unit increases the air pressure within the kiln and forces moisture-laden air out through exhaust louvres.

Air within a bulk kiln is circulated by a centrifugal blower powered by either a 3.7 or 5.6 kW electric motor. Air flow rates will vary depending upon the kiln manufacturer, however, most are in the range of 5600 to 7200 L/s.

The majority of bulk kilns are equipped with direct-fired burners fuelled by either natural gas or propane. A small percentage of bulk kilns are equipped with indirect-fired burners fuelled by no. 2 oil. Combustion efficiency of the burners range from 59% with no. 2 oil to 85% for propane or natural gas. The majority of bulk kiln burners operate in the range of 295 to 410 MJ/h input.

Bulk kilns



TOBACCO BARNS

Tobacco pack barns are used for grading and storage of tobacco as well as for equipment storage. Barn dimensions and styles vary among farms. Most barns are equipped with a heater/humidifier unit used for conditioning tobacco during grading.

A typical tobacco pack barn